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ON A POSSIBLE FUNCTION OF DISRUPTIVE APPROACH IN THE FORMATION OF METEORITES, COMETS, AND NEBULÆ.[1 2]

According to a familiar doctrine founded on the researches of Roche, Maxwell, and others, a small body passing within a certain distance (the Roche limit) of a larger dense body will be torn into fragments by differential attraction. In reality, the doctrine is applicable to the close approach of any two bodies of sufficient mass and density, but, as this more familiar case of a small body in close approach to a larger body is the one supposed to be involved in the origin of comets and certain meteorites, it will at first be taken as representative, and the wider application of the doctrine will be considered later.

The sphere defined by Roche's limit is computed on the basis of a liquid body whose cohesion is negligible, and whose self-gravitation alone is considered. It is obvious, therefore, that when cohesion is a notable factor, a small body might pass through the outermost part of this Roche sphere without suffering disruption, but that, if a nearer approach were made to the large body, fragmentation might take place. There is, therefore, a sphere within the Roche limit—which may be called the

[1] I am greatly indebted to Dr. F. R. Moulton for suggestions and criticisms, and for formulæ for certain auxiliary computations that do not appear in the paper. I am under obligations to Mr. C. E. Siebenthal for the diagrams and other aid.

[2] From The Astrophysical Journal, Vol. XIV, No. 1, July 1901.

sphere of disruption—which is applicable to solid bodies as distinguished from liquid bodies.

The size of this sphere of disruption compared with the Roche sphere depends, among other things, on the coefficient of cohesion and the size of the body to be disrupted. The coefficient of cohesion being the same, the sphere of disruption is relatively smallest when small bodies are to be disrupted, and becomes larger as the size of the body increases until it is sensibly as large as the Roche sphere. To illustrate this concretely, let disruption be supposed to take place along a diametrical section normal to the gravitative pull, dividing the body into halves. Let the bodies to be disrupted be spherical and homogeneous. The cohesion to be overcome will then obviously vary as the areas of the diametrical sections, and these areas vary as the squares of the radii of the bodies. But the masses of homogeneous spheres vary as the cubes of their radii, and the gravitative pull varies as the masses, modified by the differential tidal pull. It follows that mutual gravitation will more effectively disrupt large bodies than small ones. The limit at which the fragmentation of a solid body will take place will therefore approach more and more closely that of a fluid body as the size of the solid body becomes larger. For solid bodies of considerable dimensions, as asteroids, for example, the limit of disruption approaches sufficiently near Roche's limit to make the difference negligible in a general discussion. This will appear the more evident from the following numerical considerations.

Experimental data as to the tensile strength of rock are very limited, as the material is rarely used where tensile stresses are involved, but all the results of experimental tests given in Johnson's *Material of Construction* fall notably below 1000 pounds to the square inch, and this figure may be assumed as a liberal representative estimate. The weight of representative rock may be taken as $\frac{1}{10}$ pound per cubic inch. The tensile strength of an inch cube is therefore to its weight, at the surface of the earth, as 10,000 to 1. Using the same data, the tensile strength of a mile-cube of rock is to its weight as 1 to 6.36,

while that of a 100-mile-cube is as 1 to 636. It will be seen, therefore, that in a comparatively small body the cohesive resistance to disruption bears a very small relation to the gravity of the mass, and that for large bodies it is negligible. For such bodies, the Roche limit may be taken as appreciably the limit of the sphere of disruption.

These numerical considerations, however, show that fragmentation by differential gravity acting alone will not become minute in any such case as that of a satellite or asteroid making a near approach to one of the planets.

But there are additional considerations that influence the practical result. The outer portion of the earth, and doubtless that of the satellites, asteroids, and cold planets generally, is deeply traversed by fissures—oblique and horizontal as well as vertical—which render it little more than a pavement of dissevered blocks which could be lifted away with little resistance beyond that of gravity. The relief of pressure upon the less fissured portion below, which would follow upon the removal of the overlying fissured portion, and the sudden exposure of this under portion to a lower temperature resultant from this removal, would develop new stresses; and these would doubtless give rise to additional fissuring and further easy removal, and thus the process would be extended. It is not improbable that the sudden rending open of a sphere that is hot within and the consequent exposure of the highly heated rocks in the interior to much lower temperatures would result in sufficiently great differential contraction to minutely disrupt the fragments irrespective of differential gravitation. The central portions of a body sufficiently hot to melt at surface pressures would doubtless pass immediately into the liquid condition on the removal of the pressure of the overlying rock, and this passage might, not unlikely, take on eruptive violence by reason of the included and highly compressed gases—or substances in a potentially gaseous state—in which case an extremely minute division would ensue. In the case of the earth, there is good reason to believe that if its interior gravitative stresses were suddenly

removed, its internal elasticity would disrupt its exterior with much violence; and if the gravitative stresses were more gradually removed, the disruption would still be complete and pervasive, though less violent. How far a similar view may be entertained with reference to small bodies like the asteroids is uncertain, but even in these it is not improbable that the internal elastic factors would offset in some large part, if not entirely, the restraining force of the general cohesion of the mass.

From these considerations it would seem that the sphere of disruption, even in solid bodies of the nature of satellites and asteroids, may closely approximate to the theoretical Roche limit, while, for large bodies intensely compressed and very hot within, the practical sphere of disruption might actually exceed the Roche sphere. In the case of large gaseous bodies like the sun, intensely heated and compressed in the central portions, the disruptive or dispersive sphere must be much larger than the Roche sphere. But of this later. For the smaller solid bodies, and for present purposes, it may be assumed that the sphere of disruption is practically defined by Roche's limit.

The size of the sphere of disruption compared with the size of the body producing the disruption is an essential point in this discussion. The relative magnitude of these varies for every couplet of bodies brought under consideration, because it is dependent on density, cohesion, internal elasticity, and other varying factors. Roche has shown that, if the two bodies are incompressible fluids of the same density, and without cohesion, the limit of disruption is 2.44 times the radius of the body producing the disruption. The cross section of this body will therefore be to the cross section of the Roche sphere as 1 is to 5.95. The disk of the outer ring of *Saturn*, compared with that of the planet, whose density is unusually low, is a trifle below this ratio (1:5.29), but may be taken as a practical sanction of the figure theoretically deduced. The disk of the Earth, a dense body, is to the disk of the Roche limit, as computed by Darwin, as 1 to 7.5. It may therefore be concluded that where planets

and planet-like bodies are concerned, the sphere of disruption has a cross section from 5 to 7.5 times as great as the central body It follows from this, that to a passing body the sphere of disruption exposes a disk five to seven times as great as the central body, and hence there are from four to six times as many chances that the passing body will invade the sphere of disruption without collision, as that it will strike the central body. In other words, *the fragmentation of a small body by near approach to a large one of the nature of the planets will be from four to six times as imminent as actual collision.*

That disruptions or explosions of some kind actually take place in the heavens, and that not uncommonly, seems to be implied by the sudden appearance of new stars, often with great brilliancy, followed by rapid decline to obscurity or extinction.[1] Five such new stars have been recorded during the last decade, and the survey of the heavens during this period has not been entirely exhaustive. The appearance of such new stars has been referred to collision, but their frequency has been felt to be an objection to this view, and other explanations, of the nature of eruptions or explosions, have been offered, but usually without assigning any probable cause for such extraordinary explosive action. The numerical objection is, in some measure, removed if the possibilities of disruptive approach be added to those of collision; and it will be seen further on that special conditions giving rise to distant approaches that are merely disturbing at the outset, may ultimately give rise to large possibilities for disruptive approaches.

That bodies pass within the disruptive sphere of other bodies is known from the fact that at least four comets have been observed to pass within the Roche limit of the sun, and these would quite certainly have been torn into fragments if they had not already been in that condition. There are, therefore, some observational grounds for the view that instances of bodies passing through the disruptive spheres of other bodies are not so rare as to render their results unimportant.

[1] A fact which has become very familiar and impressive, since this was written, by the appearance of *Nova Persei.*

In the considerations now set forth, there seems to be warrant for the proposition *that solid bodies may suffer fragmentation without actual collision with other bodies, and that the bodies so disrupted may constitute comets so long as the fragments remain clustered, and that when these fragments become dispersed, they may constitute one variety of meteorites.* Only the first part of the proposition is novel—if indeed that is—for the disintegration of comets into meteorites is an accepted doctrine. The characteristics of comets other than their fragmental structure will need to be considered, but this may best be taken up later.

The foregoing conclusion, as a purely ideal proposition, does not appear to need discussion, unless the fundamental deductions of Roche, Maxwell, and others are questioned. Nor does its application to the adventitious cases of wandering bodies permit definite discussion, for neither the nature nor the number of such bodies is known; nor is the likelihood of their close approach to other bodies capable of estimation. But, on the probable supposition that the stars are centers of systems like our sun, there are hypothetical cases of approach of these systems to each other that by disturbance of the planetary orbits may lead on to disruptive approach of the individual bodies, and thus give effective application to the doctrine; and these invite consideration. It must be confessed that these cases, likewise, cannot be discussed with much satisfaction, since the movements of the assumed solar systems and their relations to each other are but very imperfectly known. Present data, however, warrant the assumption that the stars and their attendants are moving in various directions at various velocities, and that they are probably not controlled by any central body; nor do they probably follow concentric orbits so adjusted to each other as to forbid close approaches. The conception that the movements of the stars are somewhat analogous to those of the molecules of an exceedingly attenuated gas in an open space, actuated by the attraction of their common but dispersed mass, seems the most probable that can be entertained in the present state of knowledge. It may at least be made the basis for the assumptions necessary to further discuss the doctrine in hand.

Let two stars be assumed to be attended by secondaries like those of the sun, and to pass each other near enough to initiate serious disturbances in the orbits of the planets and satellites of the two systems. It is not necessary that this disturbance shall be so great as to bring about a disruptive approach of any of these bodies at once, but merely that this shall be the ulterior effect, which may be long delayed. The two systems need not necessarily invade each other's actual limit, that is, the two suns need not approach each other within the sum of the radii of the orbits of their outermost planets.[1] For example, in the ideal case of two solar systems, it is not necessary that the orbits of the two *Neptunes* shall actually cut each other. If the undisturbed orbits merely touch each other, or even closely approach each other, it seems clear that if *Neptune* be at the time coming toward the point of such ideal contact, or near approach, the attraction of the passing sun, together with *Neptune's* own momentum, will carry the planet far beyond the limit of its own ideal orbit into the sphere of dominant influence of the passing sun. At the same time, the paths of the inner orbits of both systems will be distorted in a quite irregular way, dependent on their various positions in their several orbits. The transfer of an outermost planet from one system to another under these conditions of general disturbance, or any other radical change in the orbits of the outer planets, will quite certainly lead on to other disturbances of orbit, some of which may sooner or later lead to disruptive approach, though the result of such a complication is beyond the reach of precise prediction.

A still more remote approach between two systems in which the only result is a pronounced elongation of the orbits of the two systems, may ultimately result in close approaches, for, if the orbit of any of the planets of the two systems be elongated so that its perihelion distance is less than the aphelion distance of the next inner planet, or its aphelion distance greater than the perihelion distance of the next outer planet, a disruptive

[1] In the illustrative examples it is assumed for convenience that the planes of the systems are normal to the systems' lines of movement.

approach, although it will not necessarily follow, because the planes may not coincide, and for other reasons, may result — if not at once, at least ultimately — as a consequence of the shiftings and modifications which such a disturbed condition involves. For example, it is obvious that by a favorable conjunction with a passing system whose sun is distant from *Neptune* considerably more than the radius of his orbit, there may be an elongation of the orbit of *Neptune* so as to make it cut one or more of the inner orbits, and that further modifications may arise out of these relations which will either increase or decrease the eccentricity. The principles applicable here are identical with those that have been found to produce radical modifications of the orbits of comets and that have been worked out by H. A. Newton and others.

To embrace the full possibilities of the case, it is therefore necessary to consider (1) the effects of systems passing each other at distances varying from those in which the outermost planets do not even cut each other's orbits, down to center-on-center collisions, and (2) to take account of the ulterior effects of disturbed orbits, as well as the immediate effects. This last is a consideration of no small importance in the qualitative as well as the quantitative application of the doctrine, for it distributes the effects over an indefinite period of time, and does not require their coincidence with the passage of the systems. The ulterior effects, so far as the disruption of secondaries is concerned, may apparently be much greater than the immediate effects. If this is not already clear, let a specific case be taken, as, for example, two solar systems passing each other so that their centers shall be 500,000,000 miles apart at nearest approach. If the planes of the systems are transverse to their paths, the ideal undisturbed orbits of the asteroids will touch, or closely approach, or slightly cut each other, as the individual case may be. The ideal orbits of the *Jupiters* will fall but little short of the passing sun, while the ideal orbits of *Saturn*, *Uranus*, and *Neptune* will fall outside the passing sun. While the precise results of such an event cannot be computed, it is quite certain

that the secondary systems of the two suns will be most profoundly disturbed and the symmetrical and harmonious relations of the planetary orbits be utterly broken up. While even in this case the *immediate* contingency of a disruptive approach of one secondary to another may not be high, there will arise a *perpetuated series of contingencies*, the consequences of which will apparently be immeasurably greater than those immediately incident to the disturbing action, and the end of this perpetuated series of contingencies can scarcely be foreseen. Assuming that the great planets will exercise the same kind of influence over the small planets and asteroids that pass near them that *Jupiter* does over comets, the range of possible contingencies involves, on the one hand, closer and closer approaches and even collisions with the Sun and with other planets, and, on the other hand, the development of extremely elliptical orbits that will carry the small bodies into the sphere of influence of some other system. How large a proportion of these theoretical possibilities will be realized in a given disturbed system, it is impossible to determine, for the problem is far beyond the power of mathematical analysis, but it seems at least probable that results of moment may ensue.

If we may judge from the solar system, the small bodies may be assumed to be at least fifty times as numerous as the large ones, while not improbably they are a hundred or several hundred times as numerous. Other things being equal, they should show the characteristic effects of the action under discussion with correspondingly greater frequency. But the other conditions intensify these effects. A small body may be disrupted by a large one, but not necessarily the reverse. So, too, a small body may be thrown into an erratic orbit, while the orbit of the large body may not be sensibly affected, as shown by the changes in the orbits of comets caused by *Jupiter*. By far the most common effect of the close approach of two star systems should therefore be the fragmentation of the small bodies by being caused to pass within the spheres of disruption of the large bodies. As previously indicated, *the contingency of acquiring at the same time*

highly erratic orbits is imminent, and these are specially subject to still further changes, and thus these fragmental clusters come to possess by the very circumstances of their birth the second characteristic of comets, as well as the first.

Whether they would possess at the same time, or come at length to possess, the *third* characteristic of comets, the attenuated matter of which cometic tails are made, is not so clear, since the nature of this matter and its condition are not yet fully known. The recent discoveries relative to the extreme ionization of matter and perhaps even its corpuscular dissociation, and the radio-activity of certain kinds of matter are at least very suggestive in this connection. Six of the elements reported by good authority as detected in meteorites, are known to possess, or to be habitually associated with, radio-active matter, viz., barium, bismuth, cerium, lead, titanium, and uranium. It is not very material here whether this radio-activity is really possessed by all these elements themselves, or simply by substances associated with them. If the coma and tails of comets are dependent on rare substances of a radio-active or extremely volatile nature, and hence permanently retensible only in the interior of bodies, it would be difficult to imagine conditions more favorable for setting them free in unusual volume than minute tidal disruption; particularly is this true if the retention of these substances is dependent on low temperature, as seems to be the case, since they are brought forth and driven away at a highly accelerated rate as the sun is approached. This view seems also to be supported by the fact that comets which remain long in the vicinity of the sun, as for example the short-period comets, lose their tails in a brief period.

If the attenuated cometic matter owes its essential peculiarities to electric states, these might perhaps be derivable from the revolutionary movements of the magnetic elements in the fragmental swarm, for by the hypothesis of tidal disruption the swarm should inherit a rotatory movement, and the fragments should contain both magnetic and magnetizable matter, variously associated with diamagnetic matter.

That short-period comets are subject to progressive disintegration, and that their scattered elements constitute one class of meteorites, is familiar doctrine. There seems no reason for withholding the conception from comets which have parabolic or hyperbolic orbits, for in certain cases such comets have shown signs of disruption and partial dispersion in their perihelion passages. To the dispersed elements of these comets of high velocity is assigned (in part at least) such meteorites as come to earth from diverse directions with velocities incompatible with an origin within the solar system.

It remains to consider whether the fragments derived from the disruption of an asteroid, satellite, or small planet through differential gravitative strain without collision, will satisfy the characteristics which meteorites display. Ample data for a judgment on this vital point will be found in the articles on the structure of meteorites in the first two numbers of the *Journal of Geology* for the current year, by Dr. Farrington, who, at my request, has kindly brought together in succinct and systematic form the essential characteristics of meteoric structure. A study of these characteristics will show that, while they embrace a great and very significant variety, they are all referable to the structures that are appropriate to small planets, while it is difficult to see how all of these characteristics can be found in derivatives from any of the alternative sources to which meteorites have been assigned, namely, volcanic action of the moon or of the planets, explosive projection from the sun, or individual aggregation in space. Some of the matter is fragmentary, implying surface conditions, while some of it is coarsely crystalline, implying deep-seated conditions. Some is volatile and combustible, implying the absence of high temperature throughout its whole antecedent history, while some as distinctly implies the presence of high temperature. In some meteorites the iron is segregated, while in others it is disseminated. Frequent brecciated structures imply fracturing and recementation. *Faulting and slickensides* demonstrate movements attributable to the parent body, but not to the meteorite itself. Veins imply internal

transfer and redeposit of molecules. The absence of the oxidation of the iron accords with internal conditions, and also with the supposed absence of atmospheres from small planets, asteroids, and satellites. In short, every feature of the meteorites, save, of course, the external effects of fragmentation and of heating during their fall through the atmosphere, is assignable to small planetary bodies riven into fragments without great heat and, by reason of this, retaining the varied structure attained in the parent body.

As previously indicated, the disruption of a body like the earth, the main mass of which has a temperature much above the melting point of its substances at low pressures, and which is greatly compressed within by self-gravity, would doubtless cause it to burst forth into a luminous body with perhaps some dispersive violence. The progressive stages of distortion which take origin in simple tidal protuberances and grow to greater and greater degrees of deformation and crustal fissuring, until the final stage of disruption is reached, could scarcely fail to bring some parts of the ocean into contact with some parts of the heated interior, with inevitable Krakatoan consequences. Fragments of the crust under these conditions might possibly give origin to meteorites, but the probabilities of such fragments being projected beyond the 640,000 miles of the earth's dominant influence, or beyond the similar spheres of influence of other massive planets, would not seem to be great; and, if realized, the fragments would doubtless be reduced to dust, as in the case of the Krakatoan explosion, and this state of minute division would exclude such meteorites from recognition except as vanishing shooting stars. The probabilities are that the matter of a disrupted earth or a similar massive planet would be again assembled into a planetary body by its strong self-gravity. The phenomenon would therefore be that of a temporary star. Assuming considerable dispersion, it might be rather brilliant for a time, but would rapidly cool as the result of such dispersion, and soon sink into invisibility. In the case of such a body as *Jupiter*, accepting current doctrine as to his nature, the

initial brilliancy must be much greater and the cooling to invisibility much more prolonged.[1] To phenomena of this class may perhaps be tentatively assigned certain of the temporary stars. Obviously these can only be such as had no prior visibility, and such as sink sooner or later again into invisibility. Whether this invisibility were due to the superficial cooling of the nucleus, or merely to a deep enshrouding of cooled vapor, would be immaterial.

It has already been indicated that a possible result of the serious disturbance of one solar system by the near transit of another would be a fall of some of the disturbed planets upon one of the suns. This also might be an ulterior rather than an immediate result, through the modifying effects of other planets, as well as the direct effects of the primary disturbance. Such a fall must be presumed to give rise to a notable increase of heat in the central body, as well as to mechanical effects, both of which would be conditioned by the mass and velocity of the secondary. An outburst of greater or less brilliancy must be presumed to be the result. The mechanical effects upon the sun would probably involve great changes in temporary density and condition, as well as outshoots of hot gases in various directions at high velocities. The effects might thus coincide with the phenomena of that class of the temporary stars in which a luminous state precedes and follows the outburst, and in which varying densities or high velocities in opposite directions seem to attend the temporary brilliant stage.

The disruption of suns has been neglected thus far. While, under the terms of the hypothesis, the disruption of these bodies must be rarer events than the fragmentation of the more numerous small bodies, the results must be correspondingly more important, by reason of their magnitude and character.

It has already been observed, in passing, that the internal

[1] Such a body as *Jupiter* might perhaps, under proper conditions, be dispersed in the same manner as a sun as sketched beyond.

elasticity of large hot bodies under great self-gravitative compression may so far aid in disruption, by coöperation with the differential gravity of an adjacent body, as to cause dispersion even before the Roche limit is reached. In the case of very large bodies that are already gaseous, such as the sun, this phenomenon gives rise to a special case of extreme interest. Under this special case, there arise a large variety of particular instances due to the varying sizes, velocities, paths, rotations, and constitutions of the couplets of stars concerned, and also to the adventitious effects of their secondaries; but, for a simple illustrative case, let it be assumed that two bodies of equal masses and equal velocities are approaching each other on parabolic paths, and that at periastron they will pass through each other's spheres of disruption, or rather, spheres of dispersion. For convenience, let if be assumed that one of these bodies (*A*, Fig. 1) is gaseous, while the other (*B*) has already become so cold and solid as to act essentially as a unit, though disrupted. The history of the dispersion of the gaseous body may then be followed alone. Let the rate of rotation of the gaseous body (*A*) be relatively low, as in the case of our sun. It may then be neglected in a general discussion, since as a dynamic factor it is trivial compared with the enormous energies of momentum and of elastic dispersion involved. This will appear clear in the outcome. Furthermore, the direction of rotation with reference to the parabolic paths might happen to be any one of an indefinite number, in many of which the effect would be inconsequential, even if the energy were large. In the close approach of these two bodies the two great dynamic factors of special interest are (1) the tidal distortion, and (2) the elastic expansion of the gaseous body.

While the two bodies are yet distant from each other, they must begin to take on elongation of the tidal type as the result of their mutual differential attraction, this elongation being aided by the high internal mobility and elasticity of the gaseous body. As the bodies approach periastron, this elongation must progress at an accelerated rate. At the moment of the entrance of the

gaseous body *A* upon the Roche sphere of the body *B*, self-gravitation, in accordance with Roche's doctrine, will have been completely neutralized on the lines joining the centers of *A* and *B*, and its restraining influence upon the elasticity of the gaseous body on these lines will have been removed, while the gravitative constraint in the transverse section will be increased. The expansive energy of the compressed gaseous matter will therefore be left to exert its full projectile force in the direction of the axis of elongation. While I am unable to offer a numerical estimate of the magnitude of this expansional energy in such a body as the sun, it is certainly of a high order of magnitude. The speed at which prominences are projected from the sun under present conditions closely approximates to the parabolic velocity with respect to the sun, and this is accomplished in spite of gravitation and a resisting atmosphere.

The case in hand, therefore, starts with simple tidal elongation at a distance, and increases to an explosive maximum as the bodies approach periastron. This increase is at first gradual, but in the last stages of approach to periastron the acceleration is exceedingly rapid. In any attempt to follow the process in more detail, adhering to the recognized principles of tidal action, four particulars are of special moment: (1) the progressive elongation of the body, (2) the change in the direction of tidal distortion, (3) the lag of the line of maximum elongation behind the line of maximum attraction, and (4) the rotatory effects arising from the gravitation of *B* on the tidal protuberances of *A*, which in this case will be peculiarly effective because of the enormous distortion of *A* and the very close proximity of *B* at the critical stages. The principles from which these effects arise are thoroughly demonstrated and are familiar to all students of tidal phenomena, and it is only their special applications to this case that need be discussed. The rotatory effects are a little peculiar in that both of the tidally acting bodies are rapidly approaching each other, and developing extraordinarily powerful differential attractions, while at the same time they are swinging about their common center of gravity. Near periastron they

may be regarded as performing a semi-revolution about each other. By the terms of the special case in hand, this semi-revolution must be performed in a very few hours. During these few hours the gaseous body (*A*) is undergoing elongation at a rate not much less than that represented by its full explosive

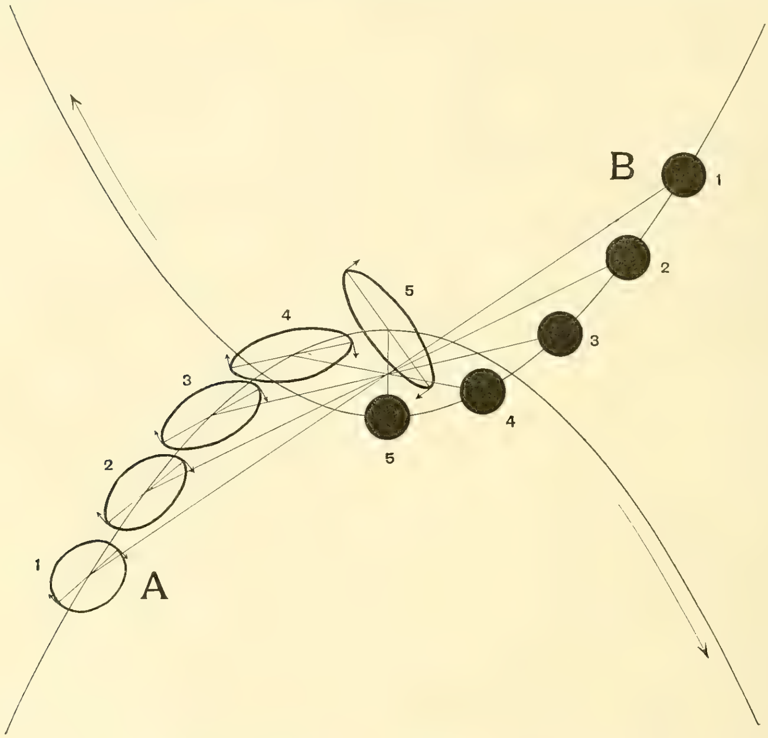


FIG. 1.—Diagram illustrating the elongating and rotatory effects of a solid stellar body, *B*, upon a gaseous sun, *A*, during their mutual approach to periastron. A $^{1, 2, 3, 4, \& 5}$ indicate successive positions, changes of form, and rotation of the gaseous star on its approach to periastron. $B^{1, 2, 3, 4, \& 5}$ represent the successive positions of a solid body of equal mass and velocity which is assumed for convenience to remain intact. Position A^1 corresponds to B^1, A^2 to B^2, etc. The lines joining their centers indicate the successive directions of mutual attraction. The arrows indicate direction of movement.

competency. The rotational forces are diagrammatically illustrated in Fig. 1, in which the lag is merely estimated and the distortion of *A* is simplified while that of *B* is neglected.

It is assumed that the lag of the axis of elongation of A is uch that the effective path of explosive projection will be directed to the rear of B. It must be noticed that if the center of A passes through the outer part of the Roche sphere of B, the nearest edge of A, if undistorted, would pass within two or three hundred thousand miles of B, and hence that the projective elongation of A must pass critically near B; but the relative speed of the bodies A and B is so great—both being near the parabolic velocity with respect to the other—that the projected matter of A can only collide with B on the supposition that the velocity of projection at least equals the parabolic velocity of the body and acts instantaneously, the last of which is impossible. This is based on the assumption that the transverse component of the attraction of B prevents the elongation of the minor axis of A, which is true of liquid bodies tidally affected, but might perhaps break down in a gaseous body under these extraordinary conditions. The point, however, is not important here, for if the edge of the projected part of A collide with B, it will only intensify the rotatory effects under consideration, and such collision is contemplated as an essential feature of the next following case, but is excluded here as the effects of *approach without collision* is the special theme under discussion.

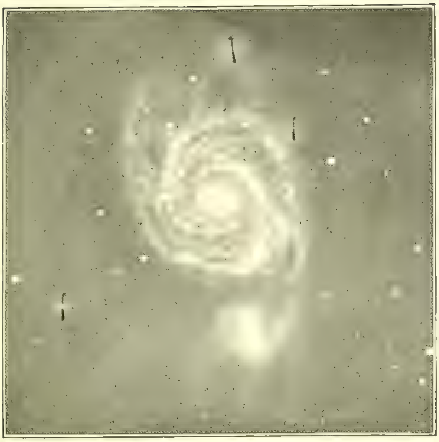
The very close approach of the elongated extremity of A to B obviously gives great effectiveness to the rotatory influence of B's attraction upon it. If the amount of this attraction be represented by the fall of $\frac{1}{1000}$ part of the mass of A toward B at a mean distance of 200,000 miles from B's surface—the masses of A and B being each equal to that of the sun—such a fall for about two hours and a half would generate a momentum equal to the whole revolutionary and rotatory momentum of the present solar system. It would appear, therefore, that under the conditions postulated a rotation of a highly effective kind must be imparted to the elongated body. It will now appear that the previous rotatory energy of the sun, which is only about 2 per cent. that of the solar system, is a negligible factor.

The history of A then takes this form: (1) A very rapid

elongation in the hour or two preceding its entrance upon the Roche sphere. (2) After entrance upon the Roche sphere, an explosive elongation actuated by the elastic energy then remaining in the body unrestrained by self-gravity in the axis of elongation. (A portion of the original elastic energy had been consumed in the previous elongation and a corresponding amount of momentum had been acquired, the larger component of which would be effective along the changed line of elongation.) (3) After passing out of the Roche sphere, the restraints of gravity begin again to be felt and rapidly increase as A and B retire from each other, but the distance to which the extremities of A have already been projected, and the new relations thereby assumed to the remaining mass of A, and to B, render the renewed gravitative influence far less effective than the original. and the projection must continue until the momentum acquired is overcome. (4) Coincident with this projection a constantly increasing rotation toward B has been generated, which possibly reached an effectiveness comparable to that of the solar system. *The effects of explosive projection combined with concurrent rotation must obviously give rise to a spiral form.*

It seems clear from the nature of the case that there would be a certain brief period when the climax of projective effects would be reached, and that a stream of material of much greater mass and velocity than at other instants would at this time be projected from the extremities of the elongated mass in both directions. There should therefore be two chief arms to the resulting spiral starting from the opposite points of the central mass and extending outward to the limits of the spiral—indeed constituting the most outlying portions of the spiral. These must be curved in a common direction by the rotation of the mass. Such predominant arms are notable features in the typical spiral nebulæ. They are well shown in Nos. 1, 2, 3, 4, 5, and 6, Plate I, all of which are reproductions from photographs furnished by the late Professor Keeler.

In the illustrative case that has just been discussed the solid body B was made to represent a convenient possible case but



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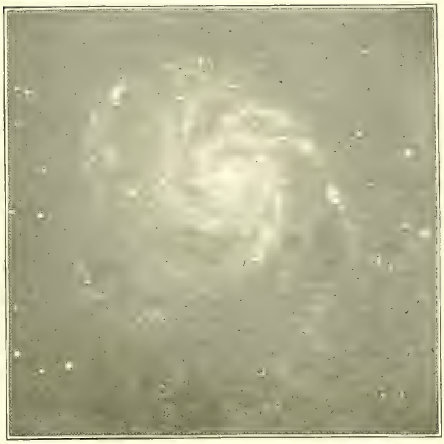

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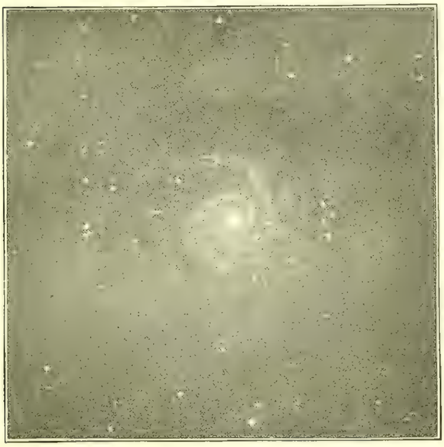

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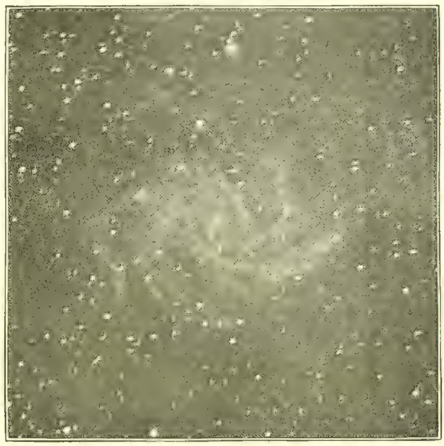

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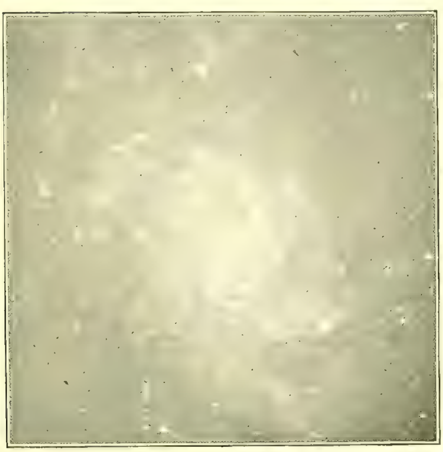

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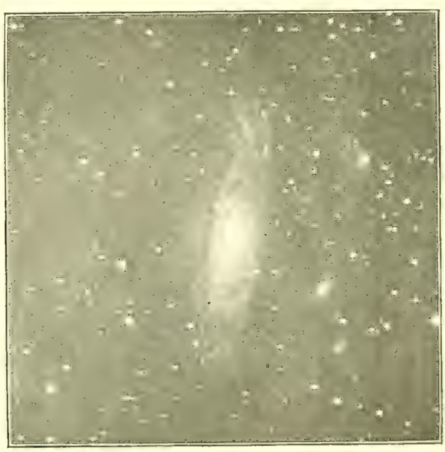

6

SPIRAL NEBULAE

1. *M 51 Can. Ven.=G. C. 3572—3574*
2. *M 101 Urs. Maj.=G. C. 3770—3771*
3. *M 74 Piscium=G. C. 372*
4. *H IV 76 Cephei=G. C. 4594*
5. *H 33 Trianguli=G. C. 352*
6. *H I 53 Pegasi* and her nebula

one whose real frequency is quite unknown, since extinct suns are beyond the reach of observation. If the active lives of suns are no greater than the periods deduced from computations founded on the Helmholtz theory of solar heat, extinct suns should either be numerous, or the whole previous history of the stellar system must have been short; or else, as a *tertium quid*, some effective means of regeneration must be assumed.

In the more typical case of two live suns coming into such close relations, its seems probable that mutual dispersion might follow without serious collision, since the analysis of the phenomena seems to show that the mutual elongations of the live suns would develop on essentially parallel lines whose constant shiftings would be mutually consonant, as illustrated in Fig. 2. If no serious contacts were developed, the two resulting spirals would separate and pursue the paths normal to their parent stars, with such modifications as may have resulted from the loss of energy involved in giving rotation to the nebulæ.

If, however, the periastron approach is so close that partial collision ensues, the analysis seems to indicate that the elongated bodies which would be developed previous to contact would not collide end to end centrally, but by a lateral shear, as illustrated in Fig. 3. In this case the arrested momentum combines with mutual attraction to give a rotatory movement of the highest order, and the heat and the resilience from impact must combine to intensify the dispersive competency. The arrest of momentum may be presumed to go so far in some cases as to cause the two bodies to unite to form a single spiral nebula of the largest and most dispersed order, such perhaps as the well-known great spiral nebulæ; or the arrest may be partial, and certain parts of one or the other, or both, of the masses may escape. In No. 1, Plate I, we seem to have a possible example of this, in which the escaping, or partially escaping, mass [1] is still associated with the longest arm of the spiral.

[1] This is assumed to have been a dead sun because of the limited evidence of explosive action.

In case the collision of two suns becomes essentially central, a general dispersion of the most violent sort may be inferred to follow, and this may find exemplification in the vast irregular nebulæ, which are in many cases more or less radiant, and in some cases consist of two irregular masses which perhaps repre-

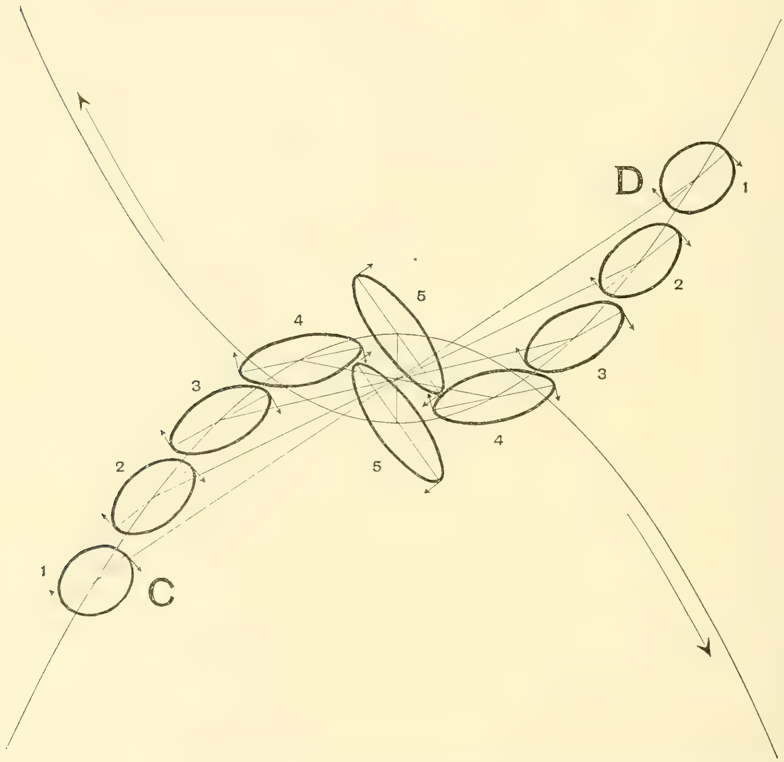

FIG. 2.—Diagram illustrating the progressive elongation and rotation of two suns, C and D, approaching perihelion. The position C^1 corresponds to D^1, C^2 to D^2, etc.; the lines joining these indicate the successive directions of mutual gravitation, and the arrows indicate direction of movement. The progressive elongation, the lag, and the rotation of the bodies at successive stages are diagrammatically indicated.

sent the wrecked originals. The collision of dead suns in which disruption shortly preceded actual impact may also play a part in forming irregular nebulæ.

Speculation may perhaps go so far as to attribute ring nebulæ

to the central penetration of a concentrated solid body through a gaseous mass.

It is as impossible as it is unnecessary to consider here the infinite variety of sub-cases which the hypothesis under consid-

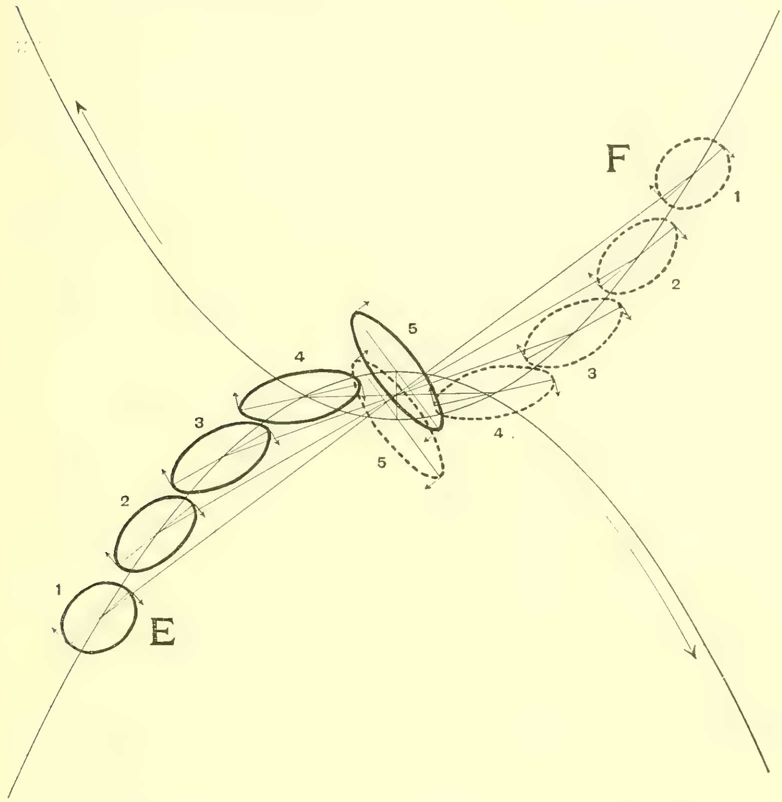

FIG. 3.—Diagram illustrating the same phenomena as Fig. 2, save that the periastron distance is so small that the bodies collide by a shearing stroke.

eration involves, but it seems advisable to note that the case of equal suns with equal velocities, which has been used in illustration, is not the most prevalent case; for inequality of mass and momentum is quite certainly the rule, rather than equality or sub-equality. Where one of the suns is much smaller than the other, the dispersive influence will be most largely felt by it,

and so it seems probable that there may be a series of cases in which the minor members of the couplets are dispersed with different intensities into complete nebulæ while the major members only suffer varying degrees of eruptive action or partial conversion into nebulæ and so perhaps become stars with nebulous adjuncts or atmospheres. Under this conception small nebulæ should be much more numerous than large ones. If large hot planets, such as Jupiter is supposed to be, are potentially gaseous, and if by disturbing approaches of stellar systems such planets are thrown out of their allegiance to their primary suns and take on comet-like courses, they would be specially liable to disruption and dispersion into small nebulæ, and would augment the number of the latter.

Whether the existing stellar movements and the mutual attractions of the stars are such as to give any substantial ground for believing that close approach can be a *chief* agency in producing comets, meteorites, and nebulæ, can only be determined when some approximate knowledge of the dispersion, the masses, the velocities, and the paths of the stars is gained. If the stars be considered simply as so many scattered bodies flying through space in straight lines at computed rates, and all mutual attractions and systematic relations be ignored, the frequency of disturbing approaches would not seem to be great and the quantitative value of the doctrine here sketched would seem to be questionable. The solar system has certainly never been subjected to disturbing approach since its present organization. But the assumptions made are certainly not the true ones and may not be representative. Besides the mere hazard of flying bodies, the mutual attraction of two stars after they enter upon each other's spheres of dominant influence — and these are very large — increases notably the probabilities of a disturbing approach even in the case of stars moving in opposed directions, while in the case of stars moving in sub-parallel and gently converging paths at sub-equal velocities, it may apparently become a dominant factor. At the average computed distances of the stars from each other, their mutual attractions are very slight, and

in the central portion of the stellar system, in which the sun seems to be placed at present, the general attractions are probably nearly balanced. Two stars, therefore, whose speeds are sub-equal and whose paths gently converge, may be controlled almost freely by their mutual attractions after they come within the spheres of each other's dominant influence. Such stars under mutual control would describe paths relative to each other similar to those assumed in the discussion. Their closeness of approach at periastron would be determined by the *relative differences* (not the total amounts) of their speeds and momenta. The principle of sub-parallel movements applies here and gives results quite at variance with those that obtain in cases of opposed movements, where the *relative sums* of the velocities and momenta are to be considered. The movements of the long-orbit comets seem to be concrete expressions of this principle, as their perihelia are largely clustered on the front side of the Sun, *i. e.*, the side toward which it is moving, and they make close approaches to it. Such star clusters as the *Pleiades*, the members of which seem to have proper movements nearly the same in amount and direction, are doubtless also expressions of the principle of sub-parallelism, and in their remarkable nebulosity they may at the same time illustrate the doctrine of disturbed secondaries leading on to dispersive action, a part of the product of which remains associated with the stars themselves, while a part is more or less widely scattered, as the terms of the doctrine require.

If our stellar system has a definite boundary and is a flattened spheroidal cluster or a discoid, and if the ideal paths of the stars are elongate orbits stretching from border to border across the heart of the cluster (except as diverted by close approaches), then the orbital speeds and momenta should be lowest on the outer surface, and the paths should there be most frequently sub-parallel, and hence the conditions for the close approach of two suns through their reciprocal attraction be there most favorable. Now, visible nebulæ are most frequent in the regions polar to the Milky Way, and they may be regarded as lying on

the flat sides or outer border of the stellar discoid where these conditions of low orbital velocity and momenta and prevalent sub-parallelism are dominant, and thus the distribution of nebulæ and the doctrine of close approach seem to be, so far at least, brought into harmony.

It may be needless to remark that the general conception lying back of the doctrine of dispersion by close approach has a complementary regenerative or reconstructive phase, which, taken with the dispersive phase, makes up a cyclic process. With the disruptive action there is correlated a reciprocal concentrative action, which is supposed to reproduce organized systems out of the wreckage of disrupted systems. The notion is further entertained that the two processes may be mutually self-adjustable, within the limits of general conditions, and thus may give a large degree of perpetuity to the existing phase of the stellar system.

T. C. CHAMBERLIN.

UNIVERSITY OF CHICAGO,
June 1901.

Studies for Students

THE CONSTITUENTS OF METEORITES. I

ELEMENTS

The following elements have by good authorities been reported as detected in meteorites by means of chemical or spectroscopic examination:

Aluminum	Helium	Potassium
Antimony	Hydrogen	Selenium
Argon	Iodine	Silicon
Arsenic	Iron	Strontium
Barium	Lead	Sodium
Bismuth	Lithium	Sulphur
Calcium	Magnesium	Thallium
Carbon	Manganese	Tin
Cerium	Molybdenum	Titanium
Chlorine	Nickel	Tungsten
Chromium	Nitrogen	Uranium
Cobalt	Oxygen	Vanadium
Copper	Palladium	Zinc
Didymium	Phosphorus	

Many of these, however, occur only as traces, while others may possibly have been introduced by terrestrial agencies. The following list will be therefore more satisfactory as giving the primary and fundamental elements known to enter into the composition of meteorites:

Aluminum	Hydrogen	Phosphorus
Calcium	Iron	Potassium
Carbon	Magnesium	Silicon
Chlorine	Manganese	Sodium
Chromium	Nickel	Sulphur
Cobalt	Nitrogen	
Copper	Oxygen	

It will be of interest to compare the more important of these in

the order of their relative abundance, with the eight most important elements of the earth's crust placed in similar order. The list of the latter is taken from Roscoe and Schorlemmer.[1]

METEORIC SERIES	TERRESTRIAL SERIES
1. Iron	1. Oxygen
2. Oxygen	2. Silicon
3. Silicon	3. Aluminum
4. Magnesium	4. Iron
5. Nickel	5. Calcium
6. Sulphur	6. Magnesium
7. Calcium	7. Sodium
8. Aluminum	8. Potassium

It should be remembered in drawing conclusions from the above list that the elements of cosmic matter in its entirety are here compared with the elements of only the crust of the earth; further, that the meteoritic matter now known probably does not show a true proportion of stony matter. As I have shown elsewhere,[2] the iron meteorites are much more likely to be known and preserved than the stony. It is probable, therefore, that if the average composition of meteoritic matter were known, iron would not occupy so high a place as it does in the above table. The relative excess of magnesium and nickel, and scarcity of aluminum and calcium in meteoritic, as compared with terrestrial, matter may be due to the same cause.

COMPOUNDS

The elements of meteorites chiefly occur combined. The exceptions are iron, nickel, cobalt, and copper, all of which occur largely in the form of alloys, carbon, and the gases, hydrogen, and nitrogen, probably held as elements in the pores of meteorites.

The compounds of meteorites according to the mineralogical names by which they are generally known, and roughly in the order of their relative abundance, are as follows, the minerals not occurring upon the earth being printed in italics:

[1] Treatise on Chemistry, Vol. I. [2] JOUR. GEOL., Vol. V, p. 126.

ESSENTIAL	ACCESSORY
Nickel-iron	Included gases
Chrysolite	Iron sulphide
Orthorhombic pyroxene	*Schreibersite*
Monoclinic pyroxene	Graphite
Plagioclase	Cohenite
Maskelynite	Glass
	Chromite
	Amorphous carbon
	Diamond
	Daubreelite
	Tridymite
	Lawrencite
	Magnetite
	Oldhamite
	Hydro carbons

A brief account will be given of each of these.

Nickel-iron.—This is the most widely distributed constituent of meteorities and in quantity it exceeds all the others combined. It makes up practically the entire mass of all the iron meteorites, the larger part of the mass of the iron-stone meteorites and is found in nearly all, though not all, the stone meteorites. It is an alloy of iron and nickel in which the percentage of nickel varies from about 6 per cent. to about 20 per cent. Some iron masses claimed to be meteorites contain a higher percentage and some authorities regard the nickel-iron of most stone meteorites as generally containing from 20 to 40 per cent. of nickel, but this is somewhat uncertain. From 0.5 to 2 per cent. of cobalt always accompanies the nickel, as well as .006 to .02 per cent. of copper. Traces of manganese and tin are also often found. The terrestrial nickel-iron of the Greenland basalts differs from that of meteorites in having a lower percentage of nickel (0.25 to 4 per cent.) and in containing a considerable amount (3 per cent.) of carbon. The terrestrial nickel-irons known as awaruite and josephinite contain higher percentages of nickel than the meteoritic, the percentages being 67.7 per cent. and 30.5 per cent. respectively. In color, meteoritic nickel-iron varies from iron or steel-gray to silver-white, according to the percentage of

nickel present. In hardness and tenacity the nickel-iron of different meteorites varies greatly. That of some meteorites is harder than steel, that of others softer than wrought iron. That of some meteorites is so brittle as to break in pieces with a blow of the hammer, that of others so malleable that it can be worked into implements of various shapes. Nickel-iron is strongly magnetic and some iron meteorites exhibit polarity due perhaps to induction of the magnetism of the earth. The specific gravity of nickel-iron ranges between 7.6 and 7.9. It is dissolved at ordinary temperatures by the common acids, by solutions of copper sulphate, by copper chloride, by mercuric chloride, by bromine water, by copper ammonium chloride, and by a few other reagents. Some masses of nickel-iron when placed in neutral solutions of copper sulphate reduce the latter, while others do not. The former are known, according to the terms first used by Wöhler, as active, the latter as passive irons. Nickel-iron oxidizes rapidly when exposed to the atmosphere, the rapidity decreasing, however, with increase in the percentage of nickel. In regard to the manner of occurrence of the nickel-iron it may be noted that in the iron meteorites it forms a compact mass except in so far as it is interrupted by inclusions of other minerals. In the iron-stone meteorites all gradations occur from a continuous network to isolated grains. In the stone meteorites it is present in the latter form. A more or less lineal arrangement of these grains, recalling Widmanstätten figures, is often observed in the stone meteorites. When the substance occurs in grains, whether large or small, the shape of these is usually very uneven, being sometimes more or less rounded but generally irregularly branching. Sometimes regular forms such as cubes and octahedrons may be observed. In the Ochansk meteorite, von Siemaschko observed actual crystals made up of a combination of the cube, octahedron, dodecahedron, and a tetrahexahedron. Other cuboidal forms have been observed. The two or possibly three subordinate alloys (kamacite, taenite, and plessite) of which nickel-iron is composed have been described in a previous article and their composition given.

Chrysolite.—This is, next to nickel-iron, the chief mineral constituent of meteorites. It is found in all the iron-stone and nearly all the stone meteorites and makes up a large part of their mass. It occurs as crystals and as rounded and angular grains. In the group of iron-stone meteorites known as pallasites it is porphyritically developed in the nickel-iron; in other iron-stone meteorites it forms together with pyroxene a granular aggregate filling the meshes of a network of nickel-iron. In the chondritic meteorites the manner of its occurrence has already been described. Crystals occurring in cavities or isolated by dissolving adjacent nickel-iron lend themselves readily to goniometric measurement. A total of twenty forms, similar to those found on terrestrial chrysolite has thus been identified. The color of the mineral is usually the typical olive-green of terrestrial chrysolite but may vary to honey-yellow or red. Much of the meteoritic chrysolite is characterized by an abundance of opaque inclusions often regularly arranged. Intergrowths with a colorless to dark brown glass are also common, especially in the chrysolite of chondritic meteorites. Gas pores are rare. Alteration products so common to terrestrial chrysolite are entirely lacking. Much of the chrysolite shows a strong tendency to fissuring, especially in thin sections. Well-marked cleavage is not common. Numerous analyses of mechanically separated chrysolite show a composition similar to that of the terrestrial mineral. The percentage of Fe in these analyses shows variations from about 10 per cent. to about 30 per cent. One feature of the composition of meteoric chrysolite which seems at first difficult to account for, is an almost entire lack of nickel oxide. This, as is well known, is a very constant constituent of terrestrial chrysolite. Daubrée has shown, however, that an absence of nickel from meteoritic chrysolite should be expected, since nickel has less affinity for oxygen than iron and would not be attacked until the latter was completely oxidized. While terrestrial iron has been completely oxidized that of meteorites has not. The correctness of this explanation has further been shown experimentally by fusing terrestrial chrysolite with pyroxene in

the presence of a reducing agent. The nickel of the chrysolite then formed an alloy with the iron of the pyroxene. The siliceous portion of meteorites that is soluble in hydrochloric acid may for the most part be considered chrysolite, since numerous analyses of this portion give results corresponding in composition to this mineral.

Orthorhombic pyroxenes.—The minerals of this group are next in abundance to chrysolite as a constituent of meteorites. They form an essential part of nearly all stone meteorites and are not lacking in the iron-stone meteorites. At least four meteorites consist of orthorhombic pyroxenes alone. These are the meteorite of Bishopville, practically composed of enstatite alone, and those of Manegaon, Ibbenbühren and Shalka, which consist essentially of hypersthene. The color of the orthorhombic pyroxenes varies from colorless through white to various shades of green. Often the mineral has the typical color of chrysolite. In thin section the pyroxene is colorless to slightly colored. Its habit is usually prismatic but it may also occur as rounded grains. Crystals with well defined planes have been observed in the Breitenbach, Bustee, Manegaon and other meteorites. A total of thirty-two forms has thus been identified and the axial relations found to correspond with those of terrestrial hypersthene. Prismatic, macrodiagonal and brachydiagonal cleavages are recognizable. It is especially characteristic of the mineral to form eccentric, radiating, polysomatic chondri, the structure of which has been described in a previous article.

Numerous chemical analyses of mechanically separated orthorhombic pyroxenes have been made. These show all gradations between the compositions represented by the formulas $MgSiO_3$ (enstatite) (Mg, Fe) SiO_3 (bronzite) and (Fe, Mg) SiO_3 (hypersthene). The portion insoluble in acids, of meteorites consisting essentially of nickel-iron, chrysolite and orthorhombic pyroxenes, may be considered to be essentially the latter, as shown by numerous analyses which give results corresponding with the pyroxene formula. The orthorhombic

pyroxenes of meteorites are thus seen to be entirely comparable to the terrestrial minerals of the same name.

Monoclinic pyroxenes.— Two kinds of monoclinic pyroxenes have been identified in meteorites, the first bearing iron and alumina, the second free from alumina and nearly free from iron. The first may be considered similar to terrestrial augite, the second to terrestrial diopside. Augite has been identified in many meteorites, diopside positively only in one. Crystals of meteoritic augite have been measured goniometrically and eight forms similar to those of terrestrial augite found. As a rule, however, the augite occurs as grains or splinters. It varies from brown to green in color, in some meteorites is pleochroic in thin section in others not at all. Parting parallel to the base, owing to repeated twinning, is common and characteristic. It is sometimes regularly intergrown with orthorhombic pyroxene. Inclusions of glass and black dust are common. Pyroxene resembling diopside was identified by Maskelyne in the Bustee meteorite. It occurred in grains and splinters and was of a gray to violet color. A few goniometric measurements were possible. Analysis showed the composition to be that of a calcium-magnesium pyroxene. Crystals and grains from a few other meteorites may perhaps be referred to diopside but the determination is not certain.

Plagioclase.—Of the minerals of the feldspar group, anorthite may be mentioned as forming an essential constituent of the classes of stone meteorites known as eukrites and howardites and as occurring in others. It forms according to Rammelsberg about 35 per cent. of the stones of Juvinas and Stannern. Of the other members of the plagioclase series, albite, oligoclase and labradorite have been reported in single meteorites, but in most cases where plagioclase has been found the species has not been determined. Orthoclase has not yet been identified in any meteorite. Crystals of anthortite from the Jonzac meteorite reach a length of 1^{cm}. From the druses of the Juvinas meteorite anorthite crystals were obtained which served for goniometric measurement, eight forms being thus identified. Some

anorthite crystals show twinning according to the Carlsbad law and in the Llano del Inca and Dona Inez meteorites twins according to the albite and pericline laws were found. The mineral is sometimes white and sometimes colorless and in luster varies from dull to vitreous. Inclusions nearly always abound and they are generally regularly arranged. The inclusions are chiefly colorless glass, but sometimes brownish glass and opaque grains occur. Analyses of mechanically isolated anorthite have been made which show a composition similar to that of terrestrial anorthite. CaO amounts to about 18 per cent. in these analyses.

Calculating from analyses Tschermak concludes the feldspar of the stone of Gopalpur to be oligoclase, Lindstrom that of Hessle to be the same and Schilling that of Tennasilm to be labradorite. The presence of plagioclase other than anorthite has been proved by microscopical and chemical examination of other meteorites, but the species have rarely been determined. Such feldspars occur as lath-shaped individuals and as grains and splinters. Inclusions are much less common than in anorthite. Rounded, elongated inclusions referred by Tschermak to chrysolite and bronzite are, however, quite characteristic. Gas inclusions seem to be more abundant in the feldspars of meteorites than in any other constituent, though even here they are rare.

Maskelynite.—This is an isotropic, colorless, though becoming milky through alteration, transparent mineral of vitreous luster and conchoidal fracture. Its hardness is somewhat over 6; specific gravity 2.65. It has no cleavage but shows occasional irregular cracks and striæ similar to those of plagioclase. Inclusions of magnetite and augite are arranged in apparent zones. The mineral is slightly decomposed by hydrochloric acid. Thin splinters fuse, but with difficulty. Lath-shaped individuals with rectangular outlines occur, but in most meteorites the mineral is present as minute grains. It forms 22½ per cent. of the meteorite of Shergotty, the remainder of the meteorite being augite and magnetite. It is also an accessory constitutent in

the meteorites of Chateau Renard, Alfianello, Milena, Mocs, and others. Its composition is about that of labradorite. Tschermak regards the mineral as a fused feldspar, while Groth and Brezina consider it a distinct species allied to leucite. Its straight, sharply defined outlines, the existence of striæ, and the absence of any fused appearance make Tschermak's view difficult to accept, though the mineral resembles the feldspars in so many other respects.

Included gases.—All meteorites which have so far been tested give off on heating one or more of the following gases: Hydrogen, carbon monoxide, carbon dioxide, nitrogen, and marsh gas. Comparing the iron meteorites with the stone meteorites in regard to the kind of gases given off it is found that the former are characterized by a high content of H and CO, the latter by an excess of CO_2. The following table of analyses of gases from eight iron and six stone meteorites, quoted from Cohen, gives an idea of the relative quantity of each gas:

	H	CO	CO_2	N	CH_4
Iron meteorites	63.09	20.70	8.12	7.52	0.57
Stone meteorites	17.55	4.15	71.66	2.20	4.17

The volumes of the gases obtained vary from 0.97 of a volume given off from the iron of Shingle Springs to 47.13 volumes collected from the Magura iron. The average number of volumes obtained from the meteorites quoted in the above table is 2.82. The gases in meteorites appear therefore to be under a somewhat greater pressure than that of the earth's atmosphere. It has often been urged that the gases obtained from meteorites by the methods above mentioned may have been absorbed from our own atmosphere. It is known on the one hand that terrestrial rocks give off on treatment gases very similar in kind and quantity to those obtained from meteorites. Thus Wright obtained from one ordinary trap rock ¾ of a volume of gas, 13 per cent. of which was CO_2 and the remainder chiefly hydrogen, and from another, one volume of gas containing 24 per cent. CO_2 and the remainder chiefly hydrogen. Tilden has also recently shown that "the crystalline rocks of the surface of the earth contain very notable quantities

of gas, consisting of hydrogen in preponderance, carbon dioxide, and carbon monoxide in large percentage, and nitrogen and marsh gas in small quantities, with water vapor, but with a practical absence of oxygen. Twenty-five analyses including ancient and modern volcanic and even some metamorphic rocks gave an average volume of gas equal to about four and one half times the volumes of the containing rocks."[1] Further, it is urged that no meteorites have been analyzed as to their gases immediately after their fall. In contrast to these facts it should be noted that the Homestead meteorite was analyzed for gases by Wright within three months from the time of its fall. A second analysis was made a year later in order to test the influence of the earth's atmosphere upon the stone. It was found that very little change had taken place except a slight *loss* of carbonic acid. Ansdell and Dewar in testing the gases of the Pultusk and Mocs meteorites chose stones of those falls which were completely incrusted so that the chances of absorption of gases from the earth's atmosphere might be reduced to a minimum. Yet the results obtained accorded well with those from other meteoric stones and for Pultusk the percentages were remarkably like those derived by Wright in a previous and independent examination of stones of the same fall. There seems, therefore, good reason to believe that the gases obtained from meteorites are brought with them from space and that they have not been derived from the earth's atmosphere.

How the gases are held by the meteorites is uncertain. Wright was inclined to believe that the pores occasionally noted in the silicates of meteorites indicated cavities where the gas was held. Such pores are of too rare occurrence, however, to meet the demands of the problem. The phenomenon seems more like the occlusion of hydrogen by platinum or zinc, and the gases are probably held partly in the intermolecular spaces and partly chemically united. Travers, however, regards them as produced by heat from the non-gaseous elements of the

[1] T. C. CHAMBERLIN: JOUR. GEOL., Vol. VII, p. 558. Quoted from Chemical News, April 9, 1897.

meteorites.[1] The magnetic and nonmagnetic or, in other words, the metallic and stony portions of the Homestead meteorite were tested separately by Wright in order to determine whether these different portions exercised any selective action in holding gases. The investigation gave the following results :

	Volumes	H	$CO+CO_2$	N
Entire stone..........	1.87	50.93	48.07	1.00
Magnetic portion, 0.51	1.48	59.38	38.72	1.90
Non-magnetic portion, 0.97.		30.96	66.96	2.08

The results show no important differences in the gases held by the different portions. By way of caution, attention should be called to the fact that the gases in meteorites may not have been originally present in the form and quantities which the analyses indicate. Thus Wright in making his analyses found CO_2 rapidly reduced to CO through contact with heated iron. Likewise, H, CO, and iron may at a moderate heat reduce the iron oxide present in many meteorites, and thus the character of each be changed. The percentages of the different gases obtained by analyses may be, therefore, more indicative than absolute.

Cohen calls attention to the fact that from artificial irons may be obtained gases corresponding both qualitatively and quantitatively to those obtained from meteoric irons. The following list of analyses illustrates this.

	H	CO	CO_2	N
White, carbonaceous cast iron..........	74.07	16.76	3.59	5.58
Mild steel............................	52.6	24.3	16.55	6.5
Ordinary gray massive charcoal iron....	38.60	49.20		12.20
Gray coke iron........................	32.70	57.90		8.40
Steel..................................	22.27	63.65	2.27	11.36

Finally it should be noted that, according to the investigations of Vogel, Wright, and Lockyer, the spectra of the gases obtained from meteorites show remarkable resemblances to the spectra of comets.

[1] Proc. Roy. Soc., Vol. LXIV, pp. 130–142.

Iron sulphide.—Troilite-pyrrhotite.—The exact form and composition of the iron sulphide which is a common ingredient in meteorites is a question not yet satisfactorily answered. For convenience, Rose's assumption that the iron sulphide of iron meteorites is troilite, that of stone meteorites pyrrhotite, is usually followed, but there are many occurrences which do not harmonize with this view.

The iron sulphide known as troilite is usually found massive, though crystals have been observed which have been referred by Brezina to the hexagonal and by Linck to the isometric system. The color varies from bronze-yellow to tomback-brown. Streak black. Hardness, 4. Specific gravity, 4.68–4.82. Generally found to be non-magnetic, although magnetic troilite has been reported. Cohen suggests that the magnetism may be due to included nickel-iron. The mineral fuses in the reducing flame to a black, magnetic globule. Decomposed by hydrochloric acid with evolution of hydrogen sulphide, but without separation of sulphur. Not affected by copper sulphate or fuming nitric acid. These reagents may be used, therefore, for its separation.

Most analyses show a composition approximating very closely to FeS. Meunier, however, obtained results more nearly in accord with the formula $Fe_{11}S_{12}$. As this is the composition of pyrrhotite he regards the two as identical. The specific gravities which he obtained, however, correspond to those observed by others for troilite, and there seems therefore, some reason to doubt the correctness of his analysis.

Troilite is almost universally present in the iron meteorites. It may be very unequally distributed in a single mass, however, being abundant in some portions and lacking in others. It usually occurs in the form of nodules, but also as plates and lamellae. The nodules vary greatly in shape and size. Rounded and oval forms are common, as are also lens and dumb-bell shapes. In Carlton a star-like form occurs. Smith separated from the Cosby's Creek iron a nodule weighing 200 grams, while one from the Magura iron measured 13^{cm} in diameter. When troilite occurs as lamellae, these are often regularly

arranged parallel to the planes of a cube. Lamellae having this arrangement are known as Reichenbach lamellae. Individual lamellae of this sort average from $0.1–0.2^{mm}$ in width and $1\frac{1}{2}–3\frac{1}{2}^{cm}$ in length. They cross layers of kamacite, and hence must have formed before these. Troilite often occurs intergrown with schreibersite and graphite, and these sometimes surround it. It also often includes nickel-iron.

The fusion and dissipation of troilite nodules during the passage of a meteorite through the atmosphere is a cause of the depressions often to be observed on the surface of both iron and stone meteorites.

The iron sulphide of the stone meteorites occurs chiefly as grains, sometimes as plates, and sometimes in vein-like forms. As mentioned in a previous article, it also occurs in chondri, frequently forming their periphery, while at other times it is in the form of grains. Crystals from the druses of the Juvinas meteorite measured by Rose proved to be hexagonal and to have forms similar to those of terrestrial pyrrhotite. It is largely on account of these observations that the iron sulphide of stone meteorites is considered to be pyrrhotite. On the other hand, the iron sulphide of stone meteorites differs from pyrrhotite in being, for the most part, non-magnetic, and in giving no free sulphur on decomposition with hydrochloric acid. Further, most analyses show a composition corresponding to the formula $Fe\,S$.

Schreibersite.—This mineral, peculiar to meteorites (if its possible occurrence in the terrestrial iron of Greenland be excepted) is also one of their most remarkable constituents, since it gives proof that the meteorites in which it occurs could not have been exposed for any long time to the action of free oxygen. The mineral is a phosphide of iron, nickel, and cobalt, having the general formula $(Fe, Ni, Co)_3\,P$, though the relative proportions of the metals vary. The normal color is tin-white, but this may readily alter to bronze-yellow or steel-gray on exposure to the air. Hardness 6.5, specific gravity 6.3–7.28. Strongly magnetic, and when magnetized retains its magnetism

for a long time. Very brittle, being thus distinguished from taenite, with which it is often confounded. Another property which distinguishes it from taenite and from cohenite is that it is insoluble in copper-ammonium chloride. It is soluble in ordinary dilute acids and in acetic acid. Does not reduce copper from a copper sulphate solution. Easily fusible before the blowpipe to a magnetic globule. It occurs as crystals, flakes, foliae, grains, and as needles. In the latter form it was long regarded a separate mineral, and was known under the name of rhabdite, but the identity of rhabdite and schreibersite has been proved by Cohen. The needles and plates often exhibit angular outlines. Individual masses of the mineral often reach a considerable size, one from the Carlton iron being 14 ^{cm}. in length. The mineral also forms a considerable portion of the mass of some meteorites, such as Bella Roca, Primitiva, and Tombigbee River. It is the most widely distributed constituent of iron meteorites, aside from nickel iron, and is believed to be usually associated with the latter mineral in the stone meteorites, though its quantity is so small that it has not often been determined. The small percentage of phosphorus usually found in the analysis of stone meteorites is generally referred to this mineral. Schreibersite has been reported in the terrestrial iron of Greenland, but its presence is not proved. Phosphides similar to schreibersite have been made in several ways artificially. The process followed has been essentially to heat iron to a high temperature together with a phosphorus-bearing compound.

Graphite.—This substance occurs in grains of sufficient size for ready examination only in the meteoric irons. In these it is usually in the form of nodules but sometimes occurs in plates or grains. The nodules often reach considerable size. One nodule taken from the Cosby's Creek iron is as large as an ordinary pear and weighs 92 grams. Even larger ones were found in the Magura iron. Toluca, Cranbourne, Chulafinnee and Mazapil are other irons which contain considerable graphite. Graphite has been estimated to form 1.17 per cent. of the mass of

Magura and 0.8 per cent. of the Cosby's Creek iron. The mineral is usually associated with iron sulphide. With this it may be intimately intergrown or the one may enclose the other. Its texture is compact rather than foliated. Smith found that the meteoric graphite oxidized much more rapidly than terrestrial graphite on treatment with nitric acid and chlorate of potash. This feature distinguishes it from the amorphous carbon separated from cast iron. The meteoritic graphite is also very pure. Although occurring in nodules of the size described, which must have segregated from the surrounding mass, the ash amounted, in an analysis made by Smith, to only 1 per cent. By ether was extracted a small quantity of a substance made up of sulphur and a hydro-carbon, which constituted the only other impurity. Emphasizing the differences between meteoritic and terrestrial graphite Smith was inclined to believe that the graphite of meteorites must have been formed by the action of bi-sulphide of carbon upon incandescent iron rather than that it was analogous in its origin to terrestrial graphite. Ansdell and Dewar, however, concluded from elaborate comparisons of meteoric and terrestrial graphite that they were similar in origin, and were formed by the action of water, gases and other agents on metal carbides. Whatever its mode of formation the occurrence of graphite in meteorites is of geological interest as proving that graphite may be formed in nature without the agency of life.

Cohenite.—This is a carbide of iron, nickel and cobalt. It has been positively identified in only a few meteorites but is doubtless of common occurrence. Its formula is $(Fe, Ni, Co)_3C$. The mineral is of metallic luster and tin-white color, though readily tarnishing to bronze-yellow. Hardness, 5.5–6. Specific gravity, 7.23–7.24. Strongly magnetic; very brittle. Insoluble in dilute hydrochloric acid and decomposed by concentrated hydrochloric acid only with difficulty. Easily soluble in copper-ammonium chloride. It occurs as isolated crystals on which several forms of the isometric system have been noted; also as grains. Elongated crystals, reaching a length of 8^{mm} are

found in the Magura meteorite. These are arranged parallel to octahedral planes. An iron carbide similar to cohenite is formed in cast iron when the latter is heated to a temperature of 600–700° C. and slowly cooled. Cohenite occurs in the terrestrial iron of Niakornak, Greenland.

OLIVER C. FARRINGTON.

(To be continued.)

THE PALEOZOIC FORMATIONS OF ALLEGANY COUNTY, MARYLAND[1]

INTRODUCTION

THE author of this paper has been engaged since the summer of 1897 as chief of the Division of Appalachian Geology of the Maryland Geological Survey in studying the geological formations of the western counties of Maryland. He has had as assistants in this work at different times Messrs. C. C. O'Harra, R. B. Rowe, G. C. Martin, A. C. McLaughlin, and A. P. Romine. Mr. Richard B. Rowe, who was already acquainted with the New York formations, reached the conclusion, as the result of his field work during 1897, that several of the Paleozoic formations of western Maryland could be correlated with those of New York. The continuation of Mr. Rowe's work, together with that of Mr. Romine, under my direction during the field seasons of 1898, 1899, and 1900 further confirmed these views.

The following account of the Paleozoic formations of Allegany county, Maryland, embraces a brief description of their character and distribution, together with a statement regarding their probable correlation with the New York and Pennsylvania formations. The report of Dr. C. C. O'Harra on "The Geology of Allegany County"[2] incorporated the revised classification of western Maryland devised by Dr. William B. Clark, the writer, and his assistants, and thus represents the conclusions, based on the field work carried on during the seasons of 1897–1900. The writer is under obligations to Professor Bailey Willis, whose manuscript on "The Appalachian Region — Paleozoic Appalachia, or the History of Maryland during Paleozoic Time,"[3] was

[1] Published by permission of Dr. William Bullock Clark, state geologist of Maryland.

[2] Md. Geol. Survey, Allegany county, 1900, pp. 57–163.

[3] Maryland Geol. Survey, Vol. IV, 1900, pp. 23–93.

kindly placed at his disposal, and has recently been published under the auspices of the state survey.

THICKNESS

The strata covering Allegany county have a thickness varying from about 13,300 to 16,000 feet. This thickness is divided between the four geological systems represented in the county in the following manner: Silurian, from 2200 to 2400 feet; Devonian, 7875 to 10,200 feet; Carboniferous, 2825 to 3000 feet, and Permian (?), about 400 feet.

SILURIAN STRATA

Juniata formation.—The oldest rocks outcropping in Allegany county belong in this formation, and are shown in only one locality. This outcrop forms the lower part of the cliffs in the gorge known as "the Narrows" just northwest of Cumberland, where Wills Creek has cut a deep and narrow trench through Wills Mountain. This gorge presents an admirable example of a narrow transverse valley where a stream has cut through a mountain ridge, and this locality has a justly deserved reputation for great natural beauty. The upper 370 feet of the formation is well shown on the northern side of the creek; but in many places in the gorge it is concealed for the most part by heavy talus of white quartzite blocks from the cliff above. In the Narrows 550 feet of the Juniata are shown, but no fossils have been found at this locality. The formation is composed of alternating beds of deep red shales and sandstones which have no regularity of succession, but show a much greater total thickness of shales than sandstones. The sandstones are hard, fine-grained, cross-bedded, and micaceous, some of the strata a foot or more in thickness, but usually less than six inches. The shales are micaceous, weathering readily, and the beds vary from an inch to six feet or more in thickness. This formation was named from the Juniata River, Pa., though in the earlier reports of that state it was termed the Medina or Levant red sandstone (No. IV*b*). It probably represents the older part of the Medina

stage of New York near the base of the Upper Silurian, which, in western New York, is composed mainly of red shales.

Tuscarora formation.—This quartzitic sandstone, which rests conformably upon the Juniata formation, and forms the beautiful flat-topped arch of Wills Mountain is admirably shown on its western side, especially at the entrance to the Narrows, and in the upper part of the high massive cliffs bordering the gorge. It also forms the greater part of the exposed rocks in Evitt's and Tussey's mountains and two small areas along the Baltimore and Ohio Railroad near Potomac Station. The formation is a white to light gray, very hard quartzose sandstone composed of fairly coarse quartz grains cemented by siliceous material. Small pebbles of quartz and also those of yellowish-green hard clay occasionally occur. The layers are frequently very massive and cross-bedded structure is not infrequent. Its thickness varies from 250 to 300 feet, and it furnishes building stone and ballast. *Arthrophycus harlani*, a sea-weed, the only fossil found in this sandstone in the county is fairly common on the upper surfaces of the higher beds in the Narrows.

The Tuscarora formation, named from Tuscarora Mountain in Pennsylvania, was formerly called the Medina or Levant white sandstone (No. IV*c*), and represents the upper part of the Medina stage of New York. The Juniata and Tuscarora formations are probably equivalent to the Medina formation of New York, but in western New York, where it is typically represented, especially in the Niagara region, there is not such a definite separation into a lower divison composed of red shales and sandstones and an upper one composed of a white quartzose sandstone as in Maryland. In the Niagara region the Medina is composed of the following divisions named in ascending order: Lower Medina, composed of red shales only about the upper 115 feet of which is exposed in outcrop. Upper Medina, composed of seven zones: (1) 25 feet of gray quartzose sandstone; (2) 25 feet of thin gray shales; (3) five feet of gray sandstones and sandy shales; (4) 6 feet of mainly gray argillaceous shales which become reddish at the top; (5) 35 to 40 feet

of mainly thin-bedded sandstone reddish in color or gray mottled with red; (6) 12 to 15 feet of massive sandstone in beds from one to several feet in thickness and varying in color from reddish to grayish; (7) at the top 7½ feet of a hard massive-bedded and compact white quartzose sandstone similar to No. 1. In some thin sandstones in the upper part of No. 6 occurs the characteristic Medina fossil known as *Arthrophycus harlani* (Conrad).[1]

Clinton formation.—The largest area of this formation flanks both sides of Wills Mountain extending to the Potomac River, while two other areas flank the southern ends of Evitt's and Tussey's mountains. The formation is composed largely of yellowish-green to reddish shales, but on weathering, the flat surfaces frequently have a scarlet tint. There are blackish shales and thin fossiliferous limestones in its upper part as well as a greenish-gray to reddish sandstone. The most important lithologic character of the formation, however, is the two beds of iron ore, the lower occurring from 120 to 160 feet above its base and consisting of two strata of iron ore separated by a band of greenish-yellow shales from 6 inches to 6 feet thick. The two ore-bearing strata have a thickness of from 10 to 12 feet. At Cumberland the upper bed of iron ore is 270 feet above the lower one, in the midst of a brownish, calcareous sandstone, nearly 3 feet thick which is directly above a massive 5-foot sandstone stratum. There are 9 inches of quite clear, fossiliferous iron ore and the overlying greenish shales and thin bands of bluish limestone also contain fossils. The thickness of the formation varies from 550 to 600 feet. Fossils are common in the middle and upper portions, some of the species being identical with those of the New York Clinton. The name is derived from the exposures at Clinton, Oneida county, N. Y., where the beds of iron ore have been mined for many years, and the stage is identical with No. V*a* of the Pennsylvania survey which is

[1] For an excellent account of the Medina formation along the Niagara River, see Bull. N. Y. State Museum, No. 45, 1901, pp. 87–95 and accompanying geological map by Dr. Amadeus W. Grabau.

called the Rockwood formation in the Piedmont folio of the U. S. Geological Survey.

Niagara formation.—This formation surrounds the three areas mentioned under the Clinton formation. The lower part consists of thin-bedded, blue limestones with thin shale partings; but in the upper part the shales predominate and become blackish in color. The thickness varies from less than 250 to fully 300 feet. The thin limestones contain brachiopods and other fossils, some of which are specifically identical with the Niagara fossils. The formation is named from the admirable exposures at Niagara Falls and represents No. V*b* of the Pennsylvania survey and the lower part of the Lewistown formation of the Piedmont folio. The revised classification of the New York series by Messrs. Clarke and Schuchert, however, drops the Niagara formation or group and returns to the earlier classification of Rochester shale, Lockport limestone, and Guelph dolomite.[1]

There has been more or less uncertainty regarding the identification of the Niagara limestone south of New York; but recently Dr. Weller has conclusively shown that the Decker Ferry formation of western New Jersey and eastern Pennsylvania is of the same age "as the Rochester shale and Lockport limestone of Clarke and Schuchert, or as the Niagara formation of most authors."[2] A small collection of fossils from the beds near Cumberland was submitted to Dr. Weller who kindly examined them and wrote that his impression is that they are the same as the Decker Ferry formation, and in New Jersey there are sufficient authentic Niagaran species to definitely refer the formation to the Niagaran. In conclusion he stated that "I should think you would be fully justified in considering the Cumberland fauna as of Niagaran age."[3] Mr. Schuchert has studied these beds in the field as well as their fossils and he positively correlates them with the Niagara. His statement is that

[1] Science, N. S., Vol. X, 1899, p. 876.

[2] Geol. Surv. N. J., Ann. Rept. for 1899–1900, p. 18, and also see p. 20.

[3] Letter of May 29, 1901.

"there are beds at Cumberland, Md., holding a fauna of the age between the Lockport [Rochester?] shale and the Guelph of New York and Ontario. This fauna has its peculiarities, but the aspect is certainly not Clinton."[1]

Salina formation.—This formation borders the Niagara but the rocks are largely concealed over most of the areas except along Wills Creek in Cumberland, Flintstone Creek at Flintstone, and the Baltimore and Ohio Railroad near Potomac Station, where one finds the best exposure. In the Potomac section there are four cement beds which have great economic value, the lowest one situated about twenty-five feet above the base of the formation. Fifty feet of the succeeding 140 feet of the formation is composed of the four cement beds which are separated by shales and impure limestones. Succeeding the upper cement bed are 450 feet or more of gray shales, drab and blue limestones and sandstone, the limestones predominating.[2] The thickness is about 700 feet. Fossils are not common. The formation was named from Salina in central New York and is represented by No, V*c* of the Pennsylvania survey and the second part of the Lewistown formation of the Piedmont folio.

The statement has been made that "the geological reader will wonder on what basis the name Salina is applied to the rocks so described" in Maryland.[3] It is perhaps sufficient to state that Professor Lesley, the former state geologist of Pennsylvania and admirable stratigraphical geologist, correlated the corresponding rocks of Pennsylvania with the Salina. In Bedford county, Pennsylvania, which lies immediately north of the Cumberland region, Professor Lesley gave the upper and middle divisions of the Salina as 628 feet in thickness to which is to be added a portion of the 472 feet composing the lower Salina

[1] Letter of June 26, 1901.

[2] Mr. Schuchert has recently studied this formation in the Cumberland region and he writes me as follows: "I am inclined to cut out of the Salina the lower 23′ 6″ as given on p. 93 of O'Harra's report (Maryland Geological Survey, Allegany county). This thickness I now refer to the rest of the Niagara. I also extend the Salina a little higher, making the total thickness 704′." (Letter of June 26, 1901.)

[3] Am. Jour. Sci., 4th ser., Vol. XI, p. 240, 1901.

which included the Niagara beds at its bottom.[1] Mr. Schuchert also fully concurs in correlating these Maryland beds with the Salina.

DEVONIAN STRATA [2]

Helderberg limestone.— The largest area covered by this formation is in the central part of the county which it enters to the north of Flintstone and then runs in a zigzag manner back and forth until it leaves the county on the western side of Evitt's Mountain. Another area follows Shriver Ridge and passes through western Cumberland across the county. A third area enters in the eastern part of Wills Creek valley and runs across the county, keeping west of Wills Mountain, to Potomac Station; and, finally, to the southwest is the Fort Hill area, beween Rawlings and Dawson. The best localities for studying this formation are the Devil's Backbone, northwest of Cumberland; the cliff on the West Virginia side at Cedar Cliff and the Baltimore and Ohio Railroad cut near Potomac Station. The lower 400 feet of the formation is composed of fairly thin-bedded bluish-gray limestones, separate pieces of which have a metallic ring when sharply hit. The more shaly layers contain fossils among which are *Tentaculites gyracanthus* and *Spirifer vanuxemi*, characteristic species of the Tentaculite limestone in New York with which this zone is correlated.

Messrs. Clarke and Schuchert in their revised classification revived Vanuxem's geographical name of Manlius limestone for the paleontological one of Tentaculite limestone.[3] The Maryland zone was put in the Helderbergian instead of the Cayugan period because, as clearly stated by Dr. O'Harra, "the lithological break between it and the Salina is very marked and can be followed in the field . . . . while there is no lithological break between the Tentaculite and Lower Pentamerus subformations, and the division for mapping purposes cannot be made here."[4]

[1] Summary Description Geol. Pennsylvania, Vol. II, p. 839, 1892.

[2] The Geological Survey of Maryland has followed Dr. Clarke and Mr. Schuchert in referring the Helderbergian period to the Devonian system.

[3] Science, N. S., Vol. X, pp. 876, 877, 1899. [4] Allegany county, p. 96.

Higher in the formation are massive darker blue limestones, about 240 feet in thickness according to Schuchert or from 50 to 150 feet as given in Rowe's report, some of the layers of which contain numerous specimens of *Pentamerus* (*Sieberella*) *galeatus*. This zone probably represents the Lower Pentamerus limestone of New York, of which the above fossil is a characteristic species.

In place of the paleontological name Lower Pentamerus limestone, Messrs. Clarke and Schuchert proposed Coeymans limestone.[1]

In the upper fifty feet or more of the limestones are frequent specimens of *Spirifer macropleurus* characteristic of the Delthyris shaly limestone of New York, with which this zone is correlated. In New York this division of the Helderberg consists of calcareous shales and shaly limestones with some beds a foot or more in thickness, but in Maryland it is composed mainly of fairly massive limestone. With the exception of the Lower Pentamerus, all the Helderberg limestones are more massive in Maryland than in New York. In place of the term Catskill or Delthyris shaly limestone Messrs. Clarke and Schuchert proposed the geographic name of New Scotland beds.[2]

The Becraft limestone, which caps the Helderberg limestone of New York, is apparently not represented in Allegany county, although some eighty-five feet of it occurs farther east in Washington county, Md.

The thickness of the foundation varies from 750 to 900 feet, and fossils are common in some of the layers. The limestones are valuable for quicklime, ballast, road-metal, and building purposes. The formation is named from the lower limestones of the Helderberg Mountains in eastern New York, and is the equivalent of No. VI of the Pennsylvania survey, and the upper part of the Lewistown formation of the Piedmont folio.

Oriskany sandstone.—The easternmost area of Oriskany sandstone is that of Stratford Ridge, to the northeast of Oldtown; then follows that of the central part of the county bordering

[1] Science, N. S., Vol. X, pp. 876, 877. [2] *Ibid.*, pp. 876, 877.

the zigzag Helderberg area; then, in order named, that crossing the county along the eastern side of Shriver Ridge; the narrow band extending across the county to the west of the Helderberg area west of Wills Mountain; to the southwest the band on the western side of Fort Hill, and, lastly, the area extending from the Twenty-first Bridge to Monster Rock at Keyser.

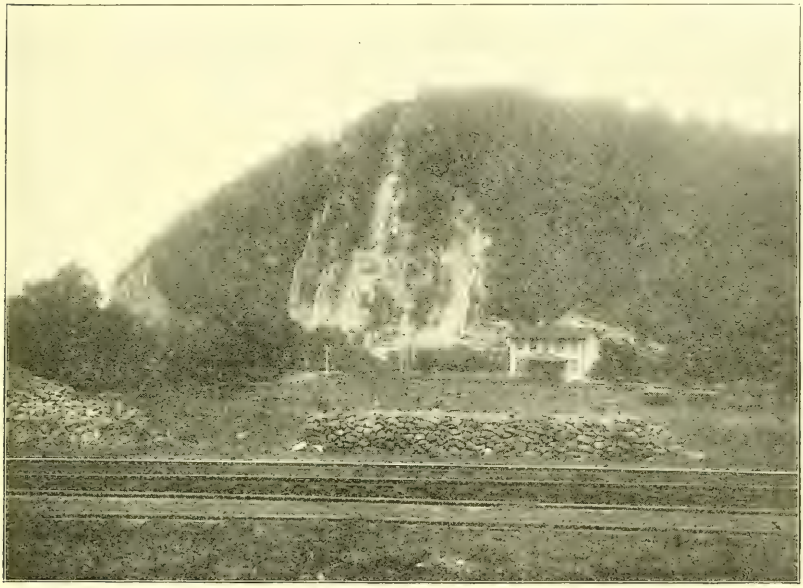

FIG. 1.—Devil's Backbone, near Cumberland, showing Helderberg limestone in the steeper part and Oriskany sandstone in the farther railroad cut.

The lower part of the formation is mainly a bluish-black cherty limestone, 75 to 100 feet in thickness, the chert in nodules and layers, with some dark gray arenaceous shales; and the remainder of the formation is mostly a sandstone, frequently calcareous, and varying in color from gray to white, about 250 feet in thickness. Toward the top there are a few bands varying from grit to conglomerate. The sandstone, on account of its calcareous cement, weathers readily to a friable brownish or buff, porous rock, which, when protected from erosion eventually forms beds of sand. Its thickness varies

from 325 to 350 feet. It furnishes railroad ballast and good glass sand. Fossils occur abundantly in zones varying in thickness from an inch to several feet. The most perfect specimens may be obtained from the beds of sand from the disintegrated rock, and frequently from pockets of sand in the partly weathered rock. *Spirifer arenosus* and other common species of the formation in New York are abundant, together with species which are restricted to its southern distribution. There are numerous springs along the contact of the Helderberg and the Oriskany sandstone. The formation is named from outcrops near Oriskany Falls, in central New York; is known as No. VII in Pennsylvania; and is the Monterey sandstone of the Piedmont folio.

Romney formation.— This formation enters the county on the eastern side of Iron Ore Ridge, northeast of Flintstone, crosses it and covers a large area to the east, north, and west of Oldtown, then alternates with the Oriskany areas in the southern central part of the county, and finally crosses in a V-shaped area — the eastern arm west of Nicholas Mountain, the point along Evitt's Creek, and the western arm passing through the eastern part of Cumberland. The western area enters the county at Ellerslie, crosses it to the Potomac River, and then extends southwest to the bend in the river at Keyser, W. Va.

The transition from the Oriskany sandsone to the black shale of the Romney is very abrupt, as may be seen at various exposures of the contact, especially east of the church on the Williams Road, two and one half miles southeast of Cumberland, and at Monster Rock on the W. Va. Central Railroad, near Keyser, W. Va. The lower part of the formation is composed of thin black shales, weathering to a rusty brown, in which are some bands of bluish-gray limestone about 150 feet above the base. This portion of the formation is well shown in the two railroad cuts just north of the Twenty-first Bridge on the Baltimore and Ohio Railroad. The black shales contain specimens of *Liorhynchus limitaris* and other small fossils, and in lithological characters agree with Marcellus shale of New York or No.

VIII*b* of Pennsylvania, which they represent. The higher rocks are drab and bluish argillaceous to arenaceous shales and thin sandstones, which usually weather to an olive or yellowish-gray tint. At certain localities they are very fossiliferous, containing numerous specimens of *Spirifer granulosus*, *S. mucronatus*, *Athyris spiriferoides*, *Tropidoleptus carinatus*, *Chonetes coronata*, *Phacops rana* and other characteristic species of the Hamilton formation of New York, the fauna amounting to about 150 species. The formation, which varies in thickness from 1600 to 1650 feet, is named from the exposures near Romney, in northeastern West Virginia, and represents the Marcellus shale and Hamilton beds of New York, and No. VIII*b* and *c* of Pennsylvania.

In 1842 Emmons proposed the name Erie group for all the New York rocks between the base of the Marcellus shales and the top of the Chemung.[1] Mr. Darton, in 1892, proposed and defined the Romney shales, named from exposures in the vicinity of Romney, Hampshire county, in northeastern West Virginia,[2] which are now known to be equivalent to the Marcellus shales and Hamilton beds of New York. Messrs. Clarke and Schuchert, in 1899, used the term Erian in their revised classification of the New York series for the group composed of the Marcellus shales and Hamilton beds, and stated that it represented the "Erie Division" revived with a restricted meaning.[3]

It appears that the Romney formation is equivalent to the Erian group of New York; but the writer is undecided as to which name the laws of nomenclature entitle to recognition in Maryland.

Jennings formation.—The eastern area crosses the eastern part of the county from the northeast to the southwest; the second area lies to the west of Green Ridge, and in its northern half covers a large district to the north and east of the Romney formation; the third covers the lower part of Evitt's Creek valley between the two arms of the V-shaped Romney area, and

[1] Geology, New York, Pt. II, pp. 100, 429.

[2] Am. Geologist, Vol. X, pp. 17, 18. [3] Science, N. S., Vol. X, pp. 876, 877.

the fourth one is the broad band covering the lower part of the eastern face of Alleghany Front and extending from the Pennsylvania line southwesterly to the Potomac River above Keyser, W. Va. The lower part of the formation composed of thin, black, argillaceous shales in which a few species, such as *Buchiola speciosa*, *Lunulicardium fragile*, and *Styliolina fissurella* are common, immediately succeeds beds containing characteristic Hamilton fossils, and is well shown on Flintstone Creek, a few rods above its mouth, opposite the old Flintstone tannery; by the side of the National Road three miles northeast of Cumberland to the west of Evitt's Creek at Folks Mill, and on the Williams road east of Cumberland. This subformation corresponds in lithologic character and stratigraphic position to the Genesee shale of New York and No. VIII*e* of Pennsylvania.

Following this are olive to bluish fine argillaceous shales alternating with thin bedded sandstones. A few fossils occur in the more bluish layers. This division of the Jennings corresponds to the Portage formation of New York, or that facies named the Naples beds by Dr. Clarke, and No. VIII*f* of Pennsylvania. Dr. J. M. Clarke, who has described the Jennings fauna for the Maryland Geological Survey, writes me that the fauna of these two lower divisions of the Jennings formation "is very distinctly that of the Naples subprovince;" and he states that the lower division is considered "as an integral part of the Naples beds, bearing the Naples fauna." [1]

Succeeding the Portage are greenish arenaceous shales weathering to a buff color alternating with thin micaceous sandstones. Occasional layers are fossiliferous and the characteristic Chemung species, *Spirifer disjunctus*, is not uncommon. The lithological appearance of this part of the formation is quite similar to that of a considerable part of the Chemung in southwestern New York. Higher the sandstones predominate, and these vary in color from yellowish-gray through brownish-gray to dark red, and vary in texture from sandstone and grits to a white pebble conglomerate. Some of these sandstones are quite

[1] Letter of June 19, 1901.

massive, and in Jennings Run about one and one half miles above Corrigansville, a zone of grit and sandstone is thirty-five feet thick. The red rocks increase above this horizon, but Chemung fossils including *Spirifer disjunctus* extend some 650 feet higher, and the line between the Jennings and Hampshire

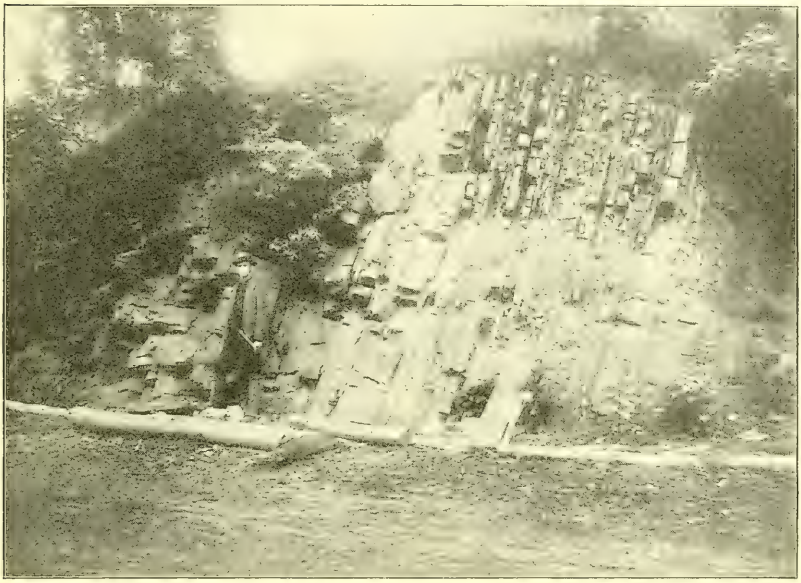

FIG. 2.—Heavy sandstone and conglomerate beds in the upper part of the Jennings formation, as shown by the roadside above Corriganville.

formations has been drawn at the top of this fauna. The formation is between 3800 and 4000 feet in thickness. The upper part of the Jennings may be correlated with the Chemung of New York or No. VIII*g* of Pennsylvania.

Hampshire formation.—This formation crosses the extreme eastern part of the county from the northeast to the southwest; the next area, which is the largest, flanks each side of Town Hill and crosses the county in the same general direction; while the third extends along the middle part of the eastern face of Alleghany Front. The rocks consist mainly of an alternation of red, flaggy, and massive sandstones and arenaceous or

argillaceous shales which both laterally and vertically merge gradually into each other and in the upper part of the formation shales, some of which are gray, and some brown in color, predominate. Some of the sandstones are crossbedded, and in the lower part of the formation, massive. The thickness varies from 1900 to 2000 feet. Fossils occur very infrequently. The formation is named from Hampshire county in northeastern West Virginia, a considerable area of which is underlain by it, and it represents at least part of the Catskill formation of New York, or No. IX of Pennsylvania.

CARBONIFEROUS STRATA

Pocono sandstone—The most eastern area of this formation, which forms the upper part of Town Hill, is mainly a massive conglomerate, while in the western area, extending across the county from Pennsylvania to West Virginia along the eastern face of Alleghany Front, the lower part of the formation is a coarse-grained, grayish-green, micaceous sandstone. Near the middle are shales containing fragments of plants, and the upper part is a grayish-green or reddish-green, micaceous, flaggy sandstone with some interbedded shales of various colors. Some of the layers are cross-bedded and others are conglomeratic. The thickness varies from 400 to 450 feet, and fragments of plants are the only fossils noted with the exception of a few shells apparently from this formation which were found nine miles northeast of Oakland, Garrett county. The formation is named from Pocono plateau in northeastern Pennsylvania, and is No. X of the Pennsylvania reports.

Greenbrier limestone.—This formation crosses the county as a narrow band along the eastern face of the Alleghany Front from Pennsylvania to West Virginia. The best exposures are in Jennings Run above the railroad water-tank; and on the north bank of the Potomac River below the mouth of Stony Run, as well as in the lower part of the run, two miles below Westernport. The lower part of the formation is composed largely of bluish-gray, arenaceous limestone, the middle of red and olive shales and the

upper part of massive bluish-gray limestones and calcareous shales. The limestone is valuable for road-metal and in Garrett county is quarried and burned to a considerable extent for quick-lime which is used as a fertilizer. The thickness varies from 200 to 250 feet and the upper part is quite fossiliferous. The

FIG. 3.—Greenbrier limestone on western bank of Youghiogheny River, southwest of Oakland, Md.

formation is named from Greenbrier county in southeastern West Virginia where it reaches a thickness of 1000 feet or more.

Mauch Chunk formation.— This, like the preceding formation, crosses the county along the eastern face of Alleghany Front but the band is broader, covering the upper part of the mountain slope. The rocks are mainly red arenaceous and argillaceous shales and sandstones, but a little above the middle of the formation is about 100 feet of reddish thin-bedded standstones. At

the top of the formation, as shown in the Cumberland and Pennsylvania R. R. cut east of Barrelville, is a greenish zone five feet thick composed partly of sandstone and partly of a calcareous breccia containing clay pebbles. The thickness of the formation is 650 feet. In the lower part of the shales and along the Greenbrier–Mauch Chunk contact are numerous excellent springs. The formation is named from Mauch Chunk in eastern Pennsylvania and is the Canaan formation of the Piedmont folio. The Greenbrier limestone and Mauch Chunk shales taken together are known as No. XI of the Pennsylvania reports.

Pottsville formation.—The preceding three formations are usually grouped together as the sub-Carboniferous or Lower Carboniferous, and the Pottsville is classed as the oldest of the Carboniferous proper or Upper Carboniferous formations. It crosses the county from Pennsylvania to the Potomac, in general forming the crest line of Alleghany Front although in the northern part it is lower, and extends up the Potomac valley to above Westernport. At numerous places near the crest line of Alleghany Front it forms conspicuous cliffs. It also occurs at the northwestern corner of the county. The formation is composed of massive light gray sandstones with some conglomerate strata and thin-bedded gray sandstones and shales. Some of the shales are black and there are several thin beds of coal. The most important are first, the Bloomington, which is exposed along the Baltimore and Ohio Railroad west of Piedmont, W. Va., commonly known as the Railroad seam, varying in thickness from less than two to more than three feet and occurring about 150 feet below the top of the formation. The second is the Westernport seam about two feet thick which occurs below the Homewood sandstone near the top of the formation. Some of the sandstones are suitable for building stone. The thickness is estimated as between 450 and 500 feet and there are fragments of fossil plants. The formation is named from the exposures of massive conglomerate in the vicinity of Pottsville in eastern Pennsylvania. It is the Blackwater formation of the Piedmont folio and No. XII of the Pennsylvania reports.

Allegheny formation.—This is the first of the Coal-measure formations and in general covers the western slope of Alleghany Front extending from Pennsylvania to the Potomac valley and up it into Garrett county. It also extends up George's Creek valley from Westernport to the vicinity of Morrison's, one mile

FIG. 4.—Block of Pottsville conglomerate, at side of National Road on top of Meadow Mountain, Garrett Co.

below Barton; and occurs in the northwestern corner of the county. The rocks consist of massive to thin-bedded grayish to olive sandstones, gray and black shales and beds of fire-clay and coal. At Barrelville and on the northern part of Dan's Mountain two coal beds occur near the base of the formation which have not been found near Westernport. The lower one, called the "Bluebaugh" (Brookville) coal, varies in thickness from 2½ to 4½ feet and 30 feet or more above it is the "Parker"

(Clarion) coal with a thickness of two feet which was reported by the miners to reach 4½ feet. At Westernport nearly 100 feet above the base is an impure coal, called the "Split six-foot" by the miners, showing a thickness of 4 feet, and 130 feet above the base is the most valuable coal seam of this formation, the "Davis" (Lower Kittanning), commonly known as the "Six-foot," with a thickness of about 5 feet in the lower George's Creek valley. Nearly 170 feet above the Davis seam is the "Thomas" (Upper Freeport) coal, which forms the top of the formation, and from its general thickness in the George's Creek valley is known as the "Three-foot" seam. Fossil shells have been found in the black or bluish shales at a few localities. The thickness of the formation is about 300 feet. It is named from the exposures on the Allegheny River in western Pennsylvania, is very generally called the Lower Productive-measures, is No. XIII of the Pennsylvania survey and includes the Savage formation and lower part of the Bayard of the Piedmont folio.

Conemaugh formation.—The area south of the Pennsylvania line to a parallel line passing through Little Alleghany and to the west of the foot of the western slope of Little Alleghany and Piney mountains is largely covered by this formation. Then it extends parallel to Dan's Mountain, to the southwestern part of the county and covers a large portion of the steep slopes of the hills bordering the lower George's Creek valley, continuing up the valley to Ocean. It also appears in the upper part of a number of the small valleys along the western border of the county. The lower part of the formation, representing the Mahoning sandstone, is frequently a massive gray sandstone with bands of yellowish shales reaching a thickness of about 100 feet. In the upper part of this sandstone, about eighty-five feet above the Thomas coal, is a coal seam about two feet in thickness underlain by a stratum of fire clay. The succeeding rocks are grayish to brownish sandstones and yellowish to gray and black arenaceous and arigillaceous shales with beds of coal and fire clay. In some of the localities there are quite massive gray to brownish-gray sandstones near the middle and top of the

formation. From 225 to 230 feet above the Thomas coal and base of the formation and about 400 feet below the Elkgarden coal is a coal seam with a general thickness of four feet, but varying from three to nearly five feet, named the Barton (Four-foot) coal, and worked to a considerable extent in the vicinity of that town. A thin seam nearly one foot thick in outcrop occurs about 440 feet above the Thomas coal or 220 feet below the Elkgarden, while approximately 500 feet above the Thomas coal and 150 feet below the Elkgarden coal is a zone composed of alternating shales and impure coal, varying in thickness from seven to ten feet, known locally as the "Dirty Nine-foot" and called the "Franklin" coal. In the Lonaconing section, thirteen feet below the base of the Franklin coal are nearly three feet of coal and black, thin shale. There are also two or three impure limestone strata and some irregular beds of iron ore. The formation is clearly defined by the top of the Thomas coal at the base and the base of the Elkgarden (Pittsburg) coal at the top, the thickness varying from 600 to nearly 640 feet. A few invertebrate fossils have been found, principally on the bank of George's Creek at Barton, and fossil plants in the black shales.

The Conemaugh formation was named from the Conemaugh River in western Pennsylvania, is frequently called the Lower Barren-measures, is No. XIV of the Pennsylvania reports, is the upper part of the Bayard and Fairfax formation of the Piedmont folio, and the Elk River series of West Virginia.

Monongahela formation.—This formation, south of an east and west line passing through Little Alleghany, covers the larger part of George's Creek valley as far south as Ocean and most of the area west to the county line. To the north of Little Alleghany, two high hills are capped by it. From Ocean to Lonaconing the upper part of the steep hills bounding the George's Creek valley are in the Monongahela, which also caps most of the highest hills as far south as Hampshire to the northeast of Westernport. The rocks consist largely of light gray to black shales with some grayish sandstones which form occasional massive strata. There are also several dark colored limestones,

bands of iron ore, and beds of coal. The Elkgarden (Pittsburg) coal, the noted seam of western Maryland, and known locally as the "Big Vein" or "Fourteen-foot" seam, occurs at the base of this formation. The main mass of coal varies in thickness from ten to nearly fourteen feet, above which are frequently from three to nine feet of alternating coal and black shale which, in the southern part of the George's Creek field, is capped by twenty-five feet of thin black shales in which coal occasionally occurs.

A seam of coal two and one half feet in thickness is reported in the Consolidation Coal Company's new shaft 92 feet above the base of the Elkgarden coal. From 120 to 140 feet above the top of the Elkgarden is the Tyson (Sewickley) coal varying in thickness from three to seven feet. Finally, at the top of the formation about 255 feet above the base of the Elkgarden coal is the Koontz (Waynesburg) coal two feet thick and reported to reach a thickness of four and one half feet. The top of this coal determines the upper limit of the Monongahela formation which has a thickness of a little more than 250 feet. Fossils are rare.

The Monongahela formation was named from the exposures along the Monongahela River in southwestern Pennsylvania, is popularly known as the Upper Productive-measures, is No. XV of the Pennsylvania reports and the Elkgarden formation of the Piedmont folio.

PERMIAN STRATA (?)

Dunkard formation.—The largest area of this formation partly underlies the city of Frostburg and covers a considerable tract to the east and southeast of the city. It covers the high part of several hills to the south of Frostburg, extending as far south as Detmold Hill on the western side of George's Creek and the hill south of Pekin on the eastern side. The rocks consist largely of argillaceous shales, which when weathered are reddish-green, with some beds of sandstone, limestone, and coal. A stratum of coal and black shale four feet thick occurs 120 feet above the base of the formation and a drab limestone, five feet

thick, weathering buff occurs about 295 feet above it. This limestone, some of the layers of which contain plenty of specimens of Ostracods (*Primatia frostburgensis* Jones) and a few other species, has been quarried to some extent toward the top of Vale's Hill, east of the Consolidation Coal Company's pumping station, and it is succeeded by thin black shales. The top of the hill is ninety feet higher and on its slope forty feet above the limestone ledge are loose pieces of bluish thin-bedded limestone containing small Ostracod and Gastropod shells. Near the top are loose blocks of coarse-grained sandstone which probably caps the hill. This hill shows about 390 feet of the Dunkard formation, which is probably its greatest thickness in the county. In addition to the fossils noted in the limestones, ferns were found in the shales overlying the Koontz coal.

The formation is named from the exposures along Dunkard Creek, near the West Virginia-Pennsylvania line, is frequently called the Upper Barren-measures, and is No. XVI of the Pennsylvania report.

CHARLES S. PROSSER.

COLUMBUS, O.,
July 1901.

THE DEPOSITION OF COPPER BY SOLUTIONS OF FERROUS SALTS

INTRODUCTORY

The genesis of the great deposits of native copper is a subject which has invited considerable speculation. From its occurrence in the cupriferous conglomerates and sandstones as a cement, or replacer, of the constituent grains, the copper is plainly of secondary origin. Its position here indicates that it resulted as a deposition from aqueous solution.[1] The metal, doubtless, first dissolved as sulphate, an oxidation-product of an original sulphide. Under the influence of solutions of calcium bicarbonate, or alkaline silicates, the sulphate was speedily converted into the carbonate, or silicate.[2] From solutions of one, or both, of these latter salts were probably derived the several classes of copper deposits.

In its paragenetic relations the position of the metallic copper indicates, as Pumpelly shows, that it was deposited after the formation of the non-alkaline silicates and before that of the alkaline silicates. As is further pointed out by the same writer, there is an intimate connection between the native copper and such iron-bearing minerals as delessite, epidote, and the green earth silicates. So constant is their common occurrence that he is led irresistibly to the conclusion that there is a close genetic relation between the reduced copper and the ferric oxide contained in the associated minerals; that, indeed, the reduction of the copper oxide to metallic copper was produced by the oxidation of ferrous derivatives. Later Irving, in support of the same view, called attention to the fact that many particles of copper enclosed a central core of magnetite.[3]

[1] R. D. Irving: Mon. U. S. Geol. Surv., No. 5 (1883), p. 420.

[2] Raphael Pumpelly: Am. Jour. Sci., Vol. II (1871), p. 353.

[3] Mon. U. S. Geol. Surv., loc. cit.

A number of attempts has been made to discover the conditions under which copper may be deposited by solutions of ferrous salts. As early as 1861, Knop succeeded in forming cuprous hydroxide by treating a mixture of cupric and ferrous sulphates with alkaline carbonate.[1] In one instance he speaks of obtaining traces of copper. In 1864, Wibel repeated Knop's experiments,[2] but was unable to verify the latter's statement regarding the reduction to metallic copper. When, however, a mixture of ferrous and cupric hydroxides, formed by adding potassium hydroxide to a solution of the sulphates, was heated to 210° C., traces of copper were obtained. Solutions of the sulphates and coarsely powdered Wollastonite, subjected to the same treatment, yielded a like result. The separation of metal, however, was slight and the part played by the ferrous hydroxide in the reduction was at the time somewhat questioned. In 1867, Braun observed the partial deposition of copper from a mixture of ferrous and cupric salts when these were dissolved in large excess of ammonium carbonate.[3] The same year Weith secured a ready reduction in the presence of tartaric acid.[4] He failed to note, however, that under the same conditions, the organic acid itself will slowly reduce the copper salt. A mixture of calcium hydroxide with a solution of ferrous and cupric sulphates, was allowed to stand for several weeks. The precipitate thus obtained, when treated with acetic acid, left a residue of cuprous oxide and copper.

Strangely enough Weith overlooked the fact that cuprous oxide with acetic acid yields cupric acetate and metallic copper. In 1869, Hunt[5] stated that he had obtained metallic copper by the action of cupric chloride on freshly precipitated ferrous hydroxide, or carbonate. Nothing is given, however, to indicate that the metal was actually detected by isolating it from co-precipitated ferric hydroxide.

[1] A. Knop: N. Jahrb. f. Min. (1861), S. 513.

[2] Ferd. Wibel: "Das Gediegen-Kupfer und das Rothkupfererz" (1864), S. 14.

[3] E. Braun: Zeit. für Chem. (1867), 569.

[4] W. Weith: Zeit. für Chem. (1867), 623.

[5] Sterry Hunt: Comp. r. (1869), 1357.

THEORETICAL

It can be shown that the deposition of copper by solutions of ferrous salts is a reversible reaction governed by the ordinary laws of chemical equilibrium. It is to Arrhenius largely that we owe the view that certain substances in solution are more, or less, dissociated into electrically charged parts, or ions. This theory has proved of the highest value in affording an insight into the principles of chemical reactions. Different substances differ much in their tendency to pass into the ionic form and this tendency is greatly influenced by external conditions, particularly by the nature of the solvent.

The chief source of ions is the dissociation of electrically neutral molecules, such as occurs in the aqueous solutions of salts, acids, and bases. They may further be formed from electrically neutral substances which enter the ionic condition by partially, or wholly, appropriating the electric charge of ions already present.[1] As an example of this mode of formation may be mentioned the reduction of ferric salts by the action of metallic iron. $2FeCl_3 + Fe = 3FeCl_2$. The solution of metallic copper in ferric chloride is an action of the same nature. $Cu + 2FeCl_3 = CuCl_2 + 2FeCl_2$.

As is seen the deposition of copper by a ferrous salt would be the reverse of this last reaction.

The conditions under which such reduction should occur may be readily determined. In a system which contains a solution of iron and cupric salts in contact with metallic copper and in which the several constituents have attained a constant value, a condition of equilibrium subsists on the one hand between ferric, cuprous, ferrous, and cupric ions ($Fe^{\cdot\cdot\cdot} + Cu^{\cdot} \rightleftarrows Fe^{\cdot\cdot} + Cu^{\cdot\cdot}$), and on the other hand between ferric, ferrous, and cuprous ions and the active mass of the metallic copper ($Cu + Fe^{\cdot\cdot\cdot} \rightleftarrows Fe^{\cdot\cdot} + Cu^{\cdot}$). If a, b, c, d, respectively, represent the active masses of the ions in the first instance, an equation of equilibrium may be thus formulated, $\frac{ab}{cd} = K$.[2] The active mass of the copper

[1] F. W. Küster: Zeit. f. Elec. Chem., Vol. IV, p. 105.

[2] W. Nernst: Theoretical Chemistry, p. 358.

is of constant value, hence in the second instance, retaining the same letters, we have the expression, $\frac{a}{bc} = K'$. The precipitation of copper would then be favored by increasing the concentration of ferrous, cuprous, and cupric ions and by decreasing that of the ferric ions. The deposition of the metal, consequently, should depend on the relative active masses of the ions present. This assumption is fully sustained by the experimental evidence which follows:

The precipitation of metallic copper by solutions of ferrous salts is a reversible action, whose direction in any case is determined by the relative concentration of the ferrous, ferric, and copper (cuprous and cupric) ions.

EXPERIMENTAL [1]

(*a*) In a solution containing an appreciable quantity of ferric ions, or in which these would be formed in the course of the reaction, metallic copper will not be deposited.

This is shown in the inability of ferrous chloride, or sulphate, to reduce corresponding copper salts, even though the mixed solutions stand for an indefinite period. This inaction is, indeed, to be expected when we consider that solutions of soluble ferric salts, as the sulphate and chloride, easily dissolve metallic copper with formation of a cupric salt.

From this it is readily understood why Wibel [2] obtained no reduction of the copper salt on heating together to 210° C. a solution of the mixed sulphates.

(*b*) In a solution containing few ferric ions and in which the reaction does not result in their appreciable increase, a sufficient concentration of ferrous and copper ions will result in the deposition of metallic copper.

The tendency of ferrous to reduce copper salts is shown in the precipitation of cuprous sulphocyanate by the action of the ammonium salt on a solution of ferrous and cupric chlorides. The same tendency appears in the formation of cuprous chloride,

[1] All the reactions given in the following paragraph have been experimentally determined by its author except as indicated by references.—Ed. JOUR. GEOL.

[2] "Das Gediegen-Kupfer und das Rothkupfrerz," S. 20.

as noted by Hunt, on heating cupric oxide with a solution of ferrous chloride.[1] From an emulsion of ferrous and cupric hydroxides, after long standing, may be separated crystals of cuprous oxide. That further reduction is largely determined by the concentration of the cupric and ferrous ions, appears probable from the action of ammonium carbonate on a solution of ferrous and cupric chlorides.[2] The precipitate first formed on adding the carbonate to the mixed chlorides, dissolves in an excess of the precipitant to a yellow liquid, from which, on standing twenty-four hours, there is deposited, on the walls of the vessel, a slight but brilliant mirror of metallic copper.

The influence of the concentration of the ions on the reduction of copper is clearly shown in the behavior of the mixed carbonates under varying conditions.

When one adds a solution of cupric and ferrous chlorides (1 mol. $CuCl_2$: 2 mol. $FeCl_2$) to a considerable excess of sodium carbonate, there is obtained a greenish precipitate of the carbonates which undergoes but slight change on standing. Such a solution, indeed, would naturally little favor the separation of metallic copper since the highly ionized alkaline carbonate would greatly decrease the active masses of the ferrous and cupric ions.

If the alkaline carbonate employed be only slightly in excess of that required to precipitate the copper and iron salts, the concentration of the carbonic acid ions will be greatly diminished. Under these more favorable conditions reduction slowly takes place with loss of carbon dioxide. The carbonates gradually change in color to a brick-red precipitate containing metallic copper and basic ferric carbonate.

As is well known the acid ferrous and cupric carbonates are more soluble than the corresponding normal or basic salts of these metals. The influence of this greater solubility is shown in the precipitation of small amounts of copper even in the presence of large excess of acid alkaline carbonates. If one adds

[1] STERRY HUNT : Comp. r., loc. cit.

[2] E. BRAUN : Zeit. für Chem., loc. cit.

the metallic chlorides to a saturated solution of acid potassium carbonate and allows the mixture to stand for twenty-four hours there is deposited on the walls of the vessel a slight film of metallic copper mixed with basic ferric carbonate.

The solubility of the acid carbonates of iron and copper is largely increased under pressure.[1] The greater concentration of the metallic ions thus obtained produces a ready reduction of copper even in the presence of concentrated solutions of the acid alkaline carbonates.

In a thick-walled flask holding a saturated solution of potassium bicarbonate is placed a tube containing a solution of ferrous and cupric chlorides. The flask is then filled with carbon dioxide, tightly sealed, and the contents of the tube mixed with the alkaline bicarbonate. The precipitate formed gradually loses carbonic acid, finally assuming the brick-red color already noted. The supernatant ruddy liquid owes its color to the presence of some basic ferric carbonate which, when the solution is warmed, deposits as ferric hydroxide. The precipitate contains finely divided copper which cannot readily be freed from the intimately associated ferric iron by treatment with hydrochloric acid because of the solvent action of ferric chloride, but on digesting the original mixture a short time a coagulum may usually be formed from which, by repeated agitation with water, the heavier metal is separated. The copper thus obtained is of characteristic appearance; is insoluble in hydrochloric acid, soluble in nitric, the solution showing the presence of copper and absence of iron.

The reduction of copper from the cuprous condition may be effected in the same manner as from the cupric. This is readily shown by substituting for the cupric salt in the above reaction cuprous chloride dissolved in a solution of chloride of sodium. From one gram of cuprous chloride more than half the metal may be easily isolated as pure copper free from ferric iron.

From these results it is quite evident that the conditions

[1] R. Wagner: Zeit. f. analyt. Chem. Vol. VI, p. 167.

under which the oxidation of ferrous salts may result in the deposition of copper are those which obtain in the circulation of underground waters. The theory of Pumpelly and others based on paragenetic relations is thus fully sustained by chemical evidence.

H. C. Biddle.

University of Chicago,
June 1901.

EVIDENCE OF A LOCAL SUBSIDENCE IN THE INTERIOR

In the spring of 1883, I made a survey to build a levee along the Wabash River on the west side of Parke county, Indiana, for a length of twelve miles. I took the levels with great care, and checked on the river water every half mile to guard against errors. The great flood of the preceding winter had left its high water mark very plain on the trees in the bottoms, and I checked on them also. I cut some sixty bench marks on the trees in running the levels, some of which are still intact. The lower end of the levee was built square across the narrow bottom to the bluff and crossed a bayou through which the flood water ran off of the bottoms into the river. We built an automatic flood-gate across this bayou so as to shut out river, but let out inside water from breaks above. The gates were hung to heavy brick walls built on timber foundations three feet thick, and deeply bedded below the bottom of the bayou. A bench mark was cut on a bur oak tree near the walls, and the level of the walls was taken when built. I had charge of the maintenance and repair of this levee four years from its building, and had frequent occasion to run the level over the top to restore breaks, for it was built only twenty-one feet above low water, whereas the great floods rise twenty-eight feet. I set the grade stakes for the contractors to work to, and in doing so ran the level over the ground again. I speak of all this to show that my leveling was correct, as so many levelings would detect any error, and none were found to exceed a half inch. I can say positively that the levels were correct in 1883.

This spring (1901) the levee was to be raised three feet, making it twenty-four feet above low water, under a new law of the state, but including only the lower seven miles. I leveled the work again, and found bench marks again intact except the

lower (south) mile and a quarter, which showed a decline southward amounting to ten inches at the lower (south) end, as shown by the mark on the bur oak and top of the gate walls. I went back to the C. & E. I. railroad bridge at Clinton, two and a half miles above the south end, and started my level from a mark known to be in tally with the level of 1883, and ran carefully over the work again, and it varied from the one made just before only a quarter of an inch. And the bench mark on the bur oak and the top of the gate walls had gone down ten inches ($\frac{83}{100}$ of a foot). I was right in 1883 and I am right now. What caused this sink, or subsidence? I can think of nothing so likely to cause it as the Charleston earthquake. The wave of that earthquake somewhere south of us changed from westward and went northward along the Wabash.

JOHN T. CAMPBELL.

ROCKVILLE, INDIANA,
July 20, 1901.

EDITORIAL

WITH the death of Dr. Joseph Le Conte there has passed away perhaps the last distinguished American representative of the general geologist as typified during the past century. This passing type of the general geologist was a distinctive outgrowth and representative of a transitional stage of intellectual procedure — a passage from the former mode in which the generalizing and philosophical factors held precedence and the toilsome modes of scientific verification followed as their servitors, to the present or at least the coming method in which scientific determinations are the basal factors to which generalizations and philosophies are but dependent accessories. We owe much of the transition itself to Dana and Le Conte, the two noblest American representatives of the passing type, for while they grew up under the influence of the older intellectual attitude, they grew out of it in spirit while they steadied and guided the transition. They were distinctively students of geology in the special sense in which that term implies the organized *doctrine* of the earth, rather than students of what might be termed *geics*, the immediate study of the earth itself in the field and the laboratory. They were preëminently students of the accumulated data and of the literature of the science, with generalization and philosophic inference as their dominant inspiration. Neither Dana nor Le Conte were eminently field students; much less were they specialists in a chosen field of the broad geological domain. Their point of view was that of the organizer and of the philosopher, and the contribution they made in their chosen sphere was indispensable and immeasurably valuable. How this necessary function is to be met in the future, with the increasing complexities and profundities into which every branch is rapidly growing, it is difficult to foresee, further than that it must in some way be intimately associated with extensive personal researches in the field and the laboratory, and must be guided

by a reversal of the old-time attitude of philosophy and science toward each other. The philosophical factor must be put into service as the active handmaid of scientific determination rather than as its guide and leader. It may indeed go before as scout to roughly reconnoiter the way, and it may come after to assemble and interpret the results, but it must ever be tentative and dependent on rigorous scientific determination. Deduction, inference, interpretation, theory, hypothesis, and the other philosophical factors must be merely initial steps and sequential steps attendant on rigorous science as the end. None the less, the philosophical factors and the philosophical point of view are indispensable if the science is to make its most wholesome progress, and we owe to Le Conte and to those he typifies an immeasurable debt, for they have kept us in fresh touch with the generalizations and the philosophy of the science, and have inspired us with their own contributions to the broader conceptions of geology and of its relations to kindred sciences. The writings of Le Conte are graced by the fruits of wide learning, a lucid style, a genial attitude, and a candor that has called forth universal love and admiration. T. C. C.

THE progress of opinion in regard to the origin of the solar system, and incidentally of the earth, is indicated by the following recent utterances of astronomers of high rank :

> This simple hypothesis (Laplace's nebular hypothesis) has recently been severely attacked, and it is doubtful whether it will survive the blow. Indeed, we may be compelled to seek the origin of stellar systems in the spiral nebulae, which Keeler's photographic survey made just before his death showed to represent a true type form. It is evident that much remains to be done before the mystery which surrounds the genesis of stars can be cleared away.— PROFESSOR GEORGE E. HALE, Director Yerkes Observatory, in address to Visiting Committee, *University Record*, June 28, 1901, p. 141.

> Though, without doubt, the system was evolved in some way from a primitive nebula, we may say with certainty that it did not follow the orderly course marked out for it by Laplace.— PROFESSOR C. L. DOOLITTLE, of the University of Pennsylvania, in annual address delivered before the University of Pennsylvania chapters of the Society of Sigma Xi, June 13, 1901, printed in *Science*, July 5, 1901, pp. 11–12.

Reviews

SUMMARIES OF CURRENT NORTH AMERICAN PRE-CAMBRIAN LITERATURE.[1]

Walcott[2] reports on the results of an examination of Cambrian and pre-Cambrian formations on Smith's Sound, Newfoundland, during the summer of 1899. At Smith point he found the Olenellus fauna 369 feet below the summit of the Etcheminian, and one of its types, Coleoloides typicalis, in the basal bed of the Cambrian, on the south side of Random Island. This retains the Etcheminian of Newfoundland in the Lower Cambrian.

The Random terrane, so-called from a typical section on Random Sound, is a series of sandstones, quartzitic sandstones, and sandy shales, resting conformably upon the Signal Hill conglomerate (which was formerly supposed to represent the top of the Avalon or Algonkian series) and extending up to the base of the Cambrian. The Random terrane is thus the upper member of the Avalon series and fills a portion, if not all, of the gap between the Signal Hill conglomerate and the Cambrian. The Cambrian rests on the Random terrane with a thin belt of conglomerate. The thickness of the terrane is probably 1000 feet. In one horizon in the terrane were found several varieties of annelid trails, including a variety about 5 millimeters broad, a slender form ½ millimeter broad, and an annulated trail 2 to 3 millimeters in width.

An examination of the form known as Aspidella terranovica found in the Momable terrane of the Avalon series proved the supposed fossil to be a spherulitic concretion, and this removes it from among the possible pre-Cambrian forms of life.

Cushing[3] describes and maps the pre-Cambrian rocks of Franklin

[1]Continued from p. 87, Vol. IX, this Journal.

[2]Random, A Pre-Cambrian Upper Algonkian Terrane, by Charles D. Walcott: Bulletin of the Geological Society of America, Vol. XI, 1900, pp. 3–5.

[3]Preliminary Report on the geology of Franklin county, Pt. III, by H. P. Cushing: Eighteenth Annual Report of the State Geologist of the State of New York, 1900, pp. 75–128. With geological map.

county, New York. These are classified as Grenville (Algonkian) rocks, igneous rocks intrusive in the Grenville, and other igneous rocks of doubtful age, possibly in part older than the Grenville rocks.

The Grenville rocks occur in small disconnected patches surrounded by intrusive igneous rocks. Some of them have such position with reference to one another that they seem to represent remnants of what were originally two continuous parallel N. E. to S. W. belts. The characteristic rock of the series is the crystalline marble. This is intricately infolded with quartzose and hornblendic gneisses, and with fine-grained granitic, syenitic, and gabbroic gneisses precisely like gneisses which occur in other areas where no member of the Grenville series is to be found.

The gneisses of undetermined age include granite, syenite, diorite, and gabbro gneisses, together with intermediate varieties. They occupy a very large area. If all these gneisses are igneous (as is thought probable) there are three possibilities in regard to their age.

1. They may represent in whole or part a more ancient series than the Grenville.

2. They may represent a somewhat later series intrusive in the Grenville, but older than the great gabbro, syenite, and granite intrusions.

3. They may represent thoroughly foliated phases of these later intrusions.

In Dr. Cushing's present judgment they will be found to belong partly under 2 and partly under 3, but more especially the former.

No rocks have been found in the northern Adirondacks which can be shown to be older than the Grenville series, but in every case in which the relations have been made out, the adjacent rocks show intrusive contacts with the Grenville rocks. On the other hand, the Grenville is a sedimentary series and must have been laid down on some floor.

Younger than the Grenville rocks and for the most part younger than the doubtful gneisses are a considerable quantity of igneous rocks comprising gabbros (anorthosites) syenites, and granites. These again occupy large areas.

In the northern portion of the county, Upper Cambrian rocks overlie the pre-Cambrian rocks with unconformity.

Smyth [1] discusses certain features of recent work in the western

[1] The Crystalline Rocks of Western Adirondack Region, by C. H. SMYTH: Rept. of the New York State Geologist for 1897, published in Fifty-first Ann. Rept. of New York State Museum, Vol. II, 1899, pp. 469–467.

Adirondack region. He concludes that the rock previously called gabbro by Nason, Van Hise, Williams, and himself, south of the belt of limestone in the Diana-Pitcaïrn area in Lewis and St. Lawrence counties, is an augite syenite of igneous origin, although it passes into a hornblende-gneiss which is unquestionably a result of dynamic action. The origin of other gneisses has been inferred to be igneous from their similarity to this gneiss which has been particularly studied, and it is evidence of this kind which serves as a basis for Smyth's conclusions, previously published,[1] that some of the gneisses on the western Adirondacks are certainly, and most of them probably, of igneous origin.

With the view of exploring the central and little known portion of the Adirondacks, a reconnaissance was made through the area contiguous to the Fulton chain of lakes and Raquette Lake in the counties of Hamilton and Herkimer. It was found that the heart of the Adirondacks is made up essentially of gneiss, with minor quantities of crystalline limestone and its associated sedimentary gneisses and schists. This is precisely analogous to what was found by the writer in St. Lawrence, Jefferson, Northern Lewis, and southwestern Hamilton counties, and by Kemp and Cushing in the eastern Adirondacks. These facts lead to the conclusion that the Adirondack region, instead of consisting of a great central mass of gabbro, surrounded by a narrow fringe of gneisses and limestones with quaquaversal dip, is essentially composed of gneisses, with numerous limestone belts, having northeast strike, and northward dip, and cut through on the east by immense intrusions of gabbro. It is still possible, of course, that some areas of gabbro may be found in the unexplored portions of the western half, but even should this be so, it would not materially modify the above conclusion, as such masses must necessarily be isolated intrusions of no great extent, rather than parts of a large area.

Kemp,[2] in connection with the description of the magnetite deposits of the Adirondacks, briefly describes the general features of the geology of the gabbro and gneiss of Westport, Elizabethtown, and Newcomb townships in Essex county, New York, and presents a geological map of the former two townships.

[1] See Summary JOUR. GEOL., Vol. VII, p. 406.

[2] The Titaniferous Iron Ores of the Adirondacks, by J. F. KEMP: Nineteenth Ann. Rept. U. S. Geol. Surv., 1897-8, Pt. III, 1899, pp. 397-399.

Kemp and Newland[1] make a preliminary report on the geology of Washington, Warren, and parts of Essex and Hamilton counties, New York. Some of the points particularly noted are:

The excessive mashing and granulation of the gneisses, giving them in places semblance to quartzite. The greenish gneisses, consisting in largest part of microperthite, were originally eruptive rocks. The discovery is reported of quartzose gneisses or foliated quartzites which are certainly metamorphosed sediments. They form notable areas along the head of South Bay, Whitehall township. Their presence indicates the probable presence of a considerable series of clastic sediments. The crystalline limestones themselves have been found in small exposures over almost all of Warren county, and generally in the crystalline belt of Washington. They are most extensive in Newcomb and Minerva townships of Essex, and to the south become thinner and more scattered. So far as we have observed they are less common in eastern Hamilton county. There is evidence to show that stratigraphical relations can be proven and that anticlines and synclines can be demonstrated.

Dikes of basic gabbro usually of moderate width, but lithologically like the larger masses in Essex county, have been met over a wide area — in fact almost every township in Warren, but the basaltic traps almost disappear.

Kemp[2] summarizes the present knowledge of the pre-Cambrian rocks of the Adirondacks. Most of the features have been covered in previous articles. Attention is called to the distribution of the sedimentary crystalline rocks, the Oswegatchie series (equivalent to the Grenville series of Adams and perhaps the Huronian). These consist of limestones, sedimentary gneisses, and quartzites. They occupy greater area than has been supposed. The limestones are found chiefly in the northwest, and the southeast or eastern portions of the Adirondack area of crystalline rocks. They are in small quantity, or altogether absent in the northern portion, in the broad belt running from

[1] Preliminary Rept. on the Geology of Washington, Warren, parts of Essex and Hamilton counties, by J. F. KEMP and D. H. NEWLAND: Rept. of the New York State Geologist for 1897, published in Fifty-first Ann. Rept., New York State Museum, Vol. II, 1899, pp. 499–553.

[2] Pre-Cambrian Sediments in the Adirondacks, by J. F. KEMP: Vice Presidential address published in the Proceedings of the A. A. A. S., Vol. XLIX, 1900, pp. 157–184.

northeast to southwest across the area, and along the southern and southwestern border. On the northwest they are in extended and comparatively broad belts, but in the eastern portion they appear in many small and separated exposures, associated with some quartzites and much greater amounts of characteristic gniesses, but greatly broken up by igneous intrusions. The quartzites thus far known are in small quantity, but such as they are, they are found principally in the eastern portions of the area, where the limestones are thinnest and most scattered. From the presence of the quartzites it is inferred that clastic sediments must have been present in larger amounts than has heretofore been realized. On the east it has not been proven that sediments form synclines pinched into the underlying gneissoid rocks. On the contrary they seem to constitute low, dipping, flat monoclines.

Comment.—The complex geology of the Adirondack crystalline rocks is being rapidly worked out by Kemp, Smyth, Cushing, and others. The frequent brief papers issued by these geologists in nearly all cases report some important advance in the solution of their problem. The precise relations of these advances to the general problem may not be clear to the average geological reader, too busily engaged to follow the subject closely, and for such the general summary of Adirondack geology given by Kemp [1] will be of value.

In a previous comment [2] on Adirondack geology the state of geological knowledge, as indicated by the literature on the subject then available, was briefly summarized by the writer, and here attention will be called only to later developments. One of the most interesting of these is the extension of the areas of pre-Cambrian sedimentary and associated rocks, and the corresponding contraction in the area of the great Adirondack gabbro. This was formerly supposed to occupy the great central area of the Adirondacks with the pre-Cambrian sediments and the associated gneisses around its periphery. Recent work seems to show that the area is occupied by gneisses, with narrow limestone belts, cut through on the east by a number of immense intrusions of gabbro. Another advance is the discovery of greater quantities of clastic sediment than have before

[1] Pre-Cambrian Sediments in the Adirondacks, by J. F. KEMP: Vice Presidential address published in Proceedings of the A. A. A. S., Vol. XLIX, 1900, pp. 157–184.

[2] JOUR. GEOL., Vol. VII, pp. 410–411.

been realized in the eastern portion of the Adirondack area, where the limestone is thinnest. The main problem of the region, the origin of the gneisses, is as yet far from settlement. The tendency is, however, to ascribe to them an igneous origin, and to place them later than the Oswegatchie series, in the areas where they have been most closely studied.

Jones,[1] in connection with a description of Tallulah Gorge of northeastern Georgia, describes the crystalline rocks there occurring, and gives a little sketch map showing their relations. They are called pre-Cambrian.

Watson[2] describes the granitic rocks of the Piedmont plateau of Georgia. Field and laboratory studies indicate that they are not all contemporaneous in origin. Some of them are pre-Cambrian, while others may possibly be later in age.

Adams[3] describes the Laurentian granitoid gneiss and granite of the Admiralty group of the Thousand Islands, Ontario. The granitoid gneiss is presumably derived by metamorphism from the granite. A large exposure of crystalline limestone on Island No. 18 resembles in all respects that of the Grenville series of the mainland adjacent.

Parks[4] describes the geology of the Moose River Basin in Canada, including the Moose and Abitibi Rivers, tributary to James Bay. This is an immense triangular area of which the apex is at James Bay, and the base stretches from above Lake Abitibi to a point west of Kabinakagami. The southern and major portion of this triangular area consists of Laurentian gneisses and granites crossed, by bands of Huronian rocks. Along the Abitibi River, Huronian rocks, consisting of altered diorites, pyrites, gray quartz schists, and some soft decomposed schists occupy the country to the south, extending as far north as the head of the first long rapid on the Frederick House River. The line of contact of this belt crosses the Abitibi below the Iroquois

[1] The Geology of the Tallulah Gorge, by S. P. JONES: American Geologist, Vol. XXVII, 1901, pp. 67–75.

[2] The Granitic Rocks of Georgia and Their Relationships, by T. L. WATSON: American Geologist, Vol. XXVII, 1901, pp. 223–225.

[3] Notes on the Geology of the Admiralty Group of the Thousand Islands, by FRANK D. ADAMS: Can. Rec. of Sci., Vol. VII, 1897, pp. 267–272.

[4] PARKS, WILLIAM A.: The Nipissing-Algoma boundary, Eighth Rept. Ont. Bur. Mines, 1899, pp. 175–204, with geological map; Niven's base line, Ninth Rept. Ont. Bur. Mines, 1900, pp. 125–142; The Huronian of the Moose River Basin, University of Toronto Studies, Geol. Series No. 1, 1900, pp. 35, with sketch map.

Falls. From this point to the Lobstick portage, Laurentian gneisses and mica schists crop out occasionally. The narrow Huronian belt from the Lobstick to the foot of the canyon or Long Portage, consists mainly of augite-syenite, passing into gabbro to the north. Beyond this portage Laurentian gneiss extends to the Devonian contact above the Sextant rapids.

Coleman[1] gives a general account of a visit to all the iron and copper regions of the Lake Superior country. For the ranges on the United States side of the boundary no facts are given not found in the published reports. On the Canadian side of the boundary the Michipicoten Range, the iron formation near Dog River, and the siliceous iron ores of Batchawana Bay are described. In the Michipicoten range the Helen mine in particular is referred to. In general, the rocks, including the ore at this mine, have all the appearance of Lower Huronian or Keewatin rocks, as in the Vermilion district, and not those of the Upper Huronian or Animikie, as in the Mesaba.

Near Dog River are iron formation rocks similar to those extending northeast from Michipicoten bay. It is thought probable that the two may connect.

The occurrence and relations of iron formation material northeast from Michipicoten Bay and near Dog River are indicated on a sketch map.

Coleman,[2] as a result of an examination of the new Michipicoten iron district, and the consideration of other iron formation areas in Ontario, has collected facts which seem to throw some light on the relative ages of the different areas mapped as Huronian on the north shore. In the Michipicoten district iron-formation material, consisting of banded ferruginous sandstones, cherts, and jaspers, standing nearly vertical, extends from Little Gros Cap northeastward for twenty miles; then bending to the north and west it takes a westerly direction for more than thirty miles. The width of the belt is but a few hundred yards.

Sandstones of the same peculiar type occur at Little Turtle Lake, east of Rainy Lake and near Fort Frances, on Rainy River, as well as at the Scramble gold mine, near Rat Portage, on Lake of the Woods.

[1] COLEMAN, DR. A. P.: Copper and Iron Regions of Ontario, by A. P. COLEMAN. Report of the Ontario Bureau of Mines for 1900, pp. 143–191.

[2] Upper and Lower Huronian in Ontario, by ARTHUR P. COLEMAN: Bull. Geol. Soc. Am., Vol. II, 1900, pp. 107–114.

Thin sections of these rocks show the same polygonal shapes of the grains of quartz, and more or less iron ore is associated with specimens from each locality. It is very probable, then, that the same horizon exists at points far to the west of Lake Superior.

Turning toward the east, specimens very like the jaspery varieties of the Michipicoten iron range are found interbedded with iron ores near Lakes Wahnapitae and Temagami, between Sudbury and the Ottawa River.

At Batchawana Bay at the southeast end of Lake Superior, a siliceous rock with narrow bands of magnetite occurs, which is probably the equivalent of the Michipicoten rock.

If, as seems probable, these jaspers are the equivalents of the western Huronian sandstones, there is a definite horizon traceable from point to point across the whole northern end of the province, a distance of more than six hundred miles.

At a number of places over this area conglomerates, containing jasper, ferruginous sandstone or chert pebbles, probably derived from the source above described, are known. Beginning at the west, some of these conglomerates occur as follows: on Shoal Lake, east of Rainy Lake; west end of Schist Lake; near Mosher Bay, at the east end of Upper Manitou Lake; a mile east of Fort Frances on the Rainy River; near Rat Portage; near the mouth of Dorè River; in the original Huronian area, north of Lake Huron, particularly the Thessalon area; on Lake Temiscaming.

It is assumed that the iron-formation material cannot be other than Lower Huronian, and that the conglomerates must represent a basal horizon of the Upper Huronian. The break between the Upper and Lower Huronian thus represented is a most profound one, and affords a good basis for the correlation of the Huronian formations. It is further suggested that this great unconformity may be the same as that between the Upper and Lower Huronian formations on the south shore of Lake Superior and in Minnesota.

Comment.—As stated by Dr. Coleman a number of the conglomerates above mentioned have been regarded by Pumpelly, Irving, Van Hise, and other United States geologists, as basal to the Lower Huronian — on structural evidence. Dr. Coleman places them in the Upper Huronian because they contain fragments of iron formation material which are assumed to be Lower Huronian. According to the generally accepted ideas of the number and relations of the pre-Cambrian

iron bearing formations, this assumption is perfectly justified and the conclusion follows as to the Upper Huronian age of the typical conglomerates mentioned.

But, lately evidence has been accumulated pointing to a conclusion of a rather radical nature. This evidence has been such that Van Hise[1] in a general article on the iron bearing formations of the Lake Superior country just published, describes *three* iron bearing formations, the Upper Huronian, Lower Huronian, and *Archean*. The most important of the Archean iron bearing formations are the Vermilion and the Michipicoten.

Van Hise himself in his published articles on the pre-Cambrian has persistently maintained the essentially non-clastic nature of the Archean, and the post-Archean age of all the iron bearing formations of the Lake Superior country. But new evidence on the subject, secured principally during the past year, has been so decisive that he has not hesitated to announce as proven the existence of an Archean or Basement Complex iron-bearing formation.

If there is an Archean iron formation, to which the Michipicoten and Vermilion iron formations belong, then Dr. Coleman's argument as to the Upper Huronian age of conglomerates containing iron formation fragments is rendered ineffective, and the conclusions indicated by the structural evidence that the great conglomerates and accompanying rocks above described are Lower Huronian must stand, until decisive evidence to the contrary is found.

Grant[2] describes and maps the Upper and Lower Keweenawan copper-bearing rocks of Douglas county, Wisconsin. The Lower Keweenawan appears in a broad belt running from northeast to southwest across the county, widening toward the southwest, and in a small belt cutting through the southeastern corner of the county. It consists mainly of basic lava flows, associated with which, in the area in the southeast corner of the county, are a few beds of conglomerate composed of débris of the closely adjacent underlying rocks. The Upper Keweenawan appears in a broad belt in the southeastern part of the county between the two belts of Lower Keweenawan rocks. It

[1] The iron-ore deposits of the Lake Superior region, by C. R. VAN HISE: Twenty-first Ann. Rept. U. S. Geol. Surv., Pt. III, 1901, p. 322.

[2] Preliminary Report on Copper Bearing Rocks in Douglas county, Wisconsin, by U. S. GRANT: Wisconsin Geological and Natural History Survey, Vol. VI, 1900, pp. 55.

is a series of conglomerates, sandstones and shales. In a belt north of the northern belt of Lower Keweenawan rocks, extending from these rocks to the shore of Lake Superior, is the Lake Superior sandstone (Cambrian). This is either flat-lying or dips slightly toward Lake Superior. The junction of the sandstone with the Lower Keweenawan is marked by a fault, along which the Lake Superior sandstone has been depressed, in some places probably as much as several hundred feet.

The Upper and Lower Keweenawan belts form a syncline, the axis of which runs northeast and southwest through the center of the tract underlain by Upper Keweenawan rocks.

While the Keweenawan rocks of this area are the same in kind and age as are the productive copper-bearing rocks of Keweenaw Point, the probable unproductive character of the Douglas county rocks is intimated.

Alexander Winchell[1] prefaces a detailed petrographical description of certain phases of the gabbroid rocks of Minnesota with a brief account of the general succession in structure of formations in northeastern Minnesota. This is essentially the same as given by N. H. Winchell[2] in Volumes IV and V of the Minnesota State Survey. The correlation of this succession with the succession determined by the United States Geological Survey is discussed.

Comment.— Mr. Winchell's ideas as to succession and structure determined by the United States Geological Survey are naturally derived mainly from Bulletin 86 of the Survey and from the "Principles of Pre-Cambrian Geology" published in the Sixteenth Annual Report of the Survey. However, since these reports have been issued, the United States Geological Survey has done somewhat detailed field work in northeastern Minnesota as a result of which the ideas of the United States geologists on the succession and correlation have been considerably changed. The new conclusions of the Survey are briefly outlined by Van Hise in the Twenty-first Annual Report. This paper should be referred to by anyone reading Mr. Winchell's discussion of the correlation.

[1] Mineralogical and Petrographic study of the gabbroid rocks of Minnesota, and more particularly of the plagioclastites, by ALEXANDER N. WINCHELL: American Geologist, Volume XXVI, 1900, General part, pp. 153–162, with geological sketch map of Northeastern Minnesota.

[2] See summaries, JOUR. GEOL., Vol. IX, pp. 79–86.

Van Hise and Bayley[1] describe and map the geology of a portion of the Menominee iron district of Michigan.

The pre-Cambrian succession is as follows:

Algonkian	Upper Menominee	Hanbury slate. Vulcan formation, subdivided into the Curry ore-bearing member, Brier slate, and Traders ore-bearing member.
	Unconformity	
	Lower Menominee	Negaunee formation. Randville dolomite. Sturgeon quartzite.
	Unconformity	
Archean	- - - -	Granites and gneisses, cut by granite and diabase dikes. Quinnesec schists, cut by acid and basic dikes and veins.

In general the Algonkian rocks constitute a trough bounded on the north by the Archean rocks.

The Archean.—The Quinnesec schists are dark green or black basic schists and spheroidal greenstones, cut by large dikes of gabbro, diabase, and granite, and by smaller dikes of a schistose quartz porphyry. These occur in two areas, one along the Menominee River to the south of the Huronian rocks, and another in the west-central end of the district.

Bordering the Algonkian trough on the north is a complex of granites, gneisses, hornblende schists, and a few greenstone schists, all cut by dikes of diabase and granite. This complex is called the "Northern Complex." Most of the Archean rocks are igneous. Although there is no evidence of this, some of the fragmental tuffs may have been water-deposited. The Quinnesec schists and the Northern Complex are called Archean because they resemble lithologically other areas of Archean rocks in the Lake Superior country, and they both underlie the Algonkian series. The Northern Complex underlies the series with unconformity. The Quinnesec schists have

[1] The Menominee special folio, by CHARLES R. VAN HISE and S. W. BAYLEY: Geological Atlas of United States, Folio No. 62, U. S. Geol. Surv., 1900.

not been observed in contact, and hence the presence or absence of a normal erosion unconformity cannot be inferred.

The Lower Menominee series.— The formations of the Lower Menominee series are observed only in the center and on the northern side of the Menominee trough. The Sturgeon formation is composed mainly of a hard white vitreous quartzite forming a continuous border of bare hills bordering the Archean complex. At its base is a coarse conglomerate made up of débris from the underlying Archean complex. The belt is in general a southward dipping monocline with dips varying from 25° to perpendicularity, although there are many reverse dips to the north. Its thickness is placed at from 1000 to 1250 feet.

Above, the Sturgeon quartzite grades into the Randville formation which is mainly a homogeneous dolomite interstratified with siliceous or argillaceous layers. This formation appears in three belts. The northern one is just south of the belt of the Sturgeon quartzite. The central belt is on the north side of Lake Antoine for a portion of its length, passes eastward between the Cuff and the Indiana mines, and ends at the bluff known as Iron Hill in the east half of Sec. 32, T. 40 N., R. 29 W. The southern belt of dolomite extends all the way from the western side of the sandstone bluff west of Iron Mountain to the village of Waucedah, at the eastern end of the mapped area. Structurally the northern belt of dolomite is a southward dipping monocline, while the two southern belts are anticlines. The thickness is not determined on satisfactory evidence, but is probably 1000 feet or more. The Randville formation is found, in a number of mines. in contact with the basal formation of the Upper Menominee series Here there is a coarse conglomerate in the basal part of the overlying formation indicating unconformity.

The Negaunee formation, overlying the Randville dolomite, is represented in the district by so few and so small outcrops that it is mapped with the Vulcan formation. Its presence is inferred mainly from the occurrence of abundant iron formation débris in the basal conglomerate of the Upper Menominee formation, showing that the Lower Menominee iron-bearing series must have been present. In the Marquette district an iron-bearing formation (the Negaunee) occupies an exactly similar stratigraphical position.

The Upper Menominee series.—The formations between the unconformity at the top of the Lower Menominee and the unconformity at

the base of the Lake Superior sandstone, are placed in the Upper Menominee series. These occur in two great series, the Vulcan and the Hanbury.

The Vulcan formation is unconformable above the upper part of the Lower Huronian, which for most of the district is the Randville formation, and unconformable below the Hanbury slate. For parts of the district the Vulcan iron-bearing formation does not appear at all between the dolomite and the slate and its absence is explained by the unconformity between the Vulcan formation and the Hanbury slate. The Vulcan formation embraces three members. These are, from the base up, the Traders iron-bearing member, the Brier slate, and the Curry iron-bearing member. They are mapped as a single formation. The principal area of the Vulcan iron formation is in the belt 900 to 1300 feet wide, following the sinuosities of the southern border of the southern belt of Randville dolomite. It is generally absent north of the southern belt except at the east end where it appears at the Loretto mine and eastward. The second important area of Vulcan iron formation stretches off about five miles along the south side of the central dolomite belt running north of Lakes Antoine and Fumee, and ending somewhere about the east line of Range 30 West. At the east end of the dolomite area the iron-bearing formation appears in the lean slates at Iron Hill. The third stretch of country in which the iron-bearing beds are to be expected is that which borders the northern dolomite belt, but while pits have shown the existence of the formation here its distribution is unknown. The other areas in which the Vulcan formation may occur are those bordering the Quinnesec schists, but this has not yet been determined.

The Traders member consists of ferruginous conglomerate, ferruginous quartzite, heavily ferruginous quartzose slates and iron ore deposits. The Brier member consists of heavy black ferruginous and quartzose slates. The Curry member consists of interbedded japsilite, ferruginous quartzose slates and iron ore deposits. The relations of the Traders and Brier Hill members where there has been no disturbance of the strata is that of gradation. Where there has been disturbance, as in the vicinity of Norway, there has been a zone of differential movement between the two, resulting in slickensides and brecciated zones. Between the Brier slates and the Curry member there is gradation.

The Vulcan formation is bent into folds of several orders of

magnitude, the greater ones corresponding approximately to the folds in the underlying Randville dolomite. The total thickness of the formation is probably 600 to 700 feet.

The iron ore deposits of large size rest upon relatively impervious formations, which are in such positions as to constitute pitching troughs. A pitching trough may be made (*a*) by the dolomite formation underlying the Traders member of the Vulcan formations, (*b*) by a slate constituting the lower part of the Traders member, and (*c*) by the Brier slate between the Traders and Curry members of the Vulcan formation. The dolomite formation is especially likely to furnish an impervious basement where its upper horizon has been transformed into a talc-schist, as a consequence of folding and shearing between the formations.

Unconformably above the Vulcan iron formation is the Hanbury formation, which forms three large belts in the syncline of the older rocks, and occupies a very large proportion of the district. The formation comprises clay slates, calcareous slates, graphite slates, graywackes, quartzite, ferruginous dolomite, and rare bodies of ferruginous chert and iron oxide. The formation is much thicker than any of the other formations of the district, but it is probably not thicker than 2000 or 3000 feet.

Wilder[1] describes and maps the Sioux quartzites and quartz porphyries of Lyon county, Iowa. No points concerning the stratigraphy or age have been added to those already given by other writers.

Bain[2] describes the geology of the Wichita Mountains. Gabbros and porphyries of pre-Cambrian and probably of Archean age are present. The gabbro is more prominent in the western portion of the mountains, being especially well-developed in the Raggedy Mountains, and the porphyry is more common in the eastern part of the mountains, being typically developed at Carrollton Mountain.

Matthews[3] gives a detailed petrographical description of the granites of the Pike's Peak quadrangle of Colorado. They are referred to the late Algonkian period.

[1] Geology of Lyon county, by FRANK A. WILDER: Iowa Geol. Surv., Vol. X, 1899, pp. 96–108.

[2] Geology of Wichita Mountains, by H. FOSTER BAIN: Bull. Geol. Soc. Am., Vol. XI, 1900, pp. 127–144, Pls. XV–XVII.

[3] The Granite Rocks of the Pike's Peak Quadrangle, by A. B. MATTHEWS: JOUR. GEOL., Vol. VIII, 1900, pp. 214–240.

Cross[1] maps and describes the geology of the Telluride quadrangle, Colorado, and briefly sketches the geology of the San Juan region, of which the Telluride quadrangle is a part.

In the Telluride quadrangle, along Canyon Creek north of Stony Mountain, is a small body of upturned quartzites, with an intercalated rhyolite sheet, which have been referred to the Algonkian. The quartzites are coarse and grade into fine conglomerate.

Ancient granites, gneisses, and schists are known in the Animas Valley and in the Uncompahgre plateau. These rocks have usually been considered as belonging to the Archean, but some of them are probably younger than the great series of quartzites exhibited in the Needle Mountains to the south, and younger than the quartzites beneath the volcanics in the canyons of the Uncompahgre, above Ouray, which have been referred to the Algonkian. These quartzites stand on edge or have been greatly disturbed. The relations of these isolated exposures to contemporaneous formations elsewhere are unknown.

Spurr[2] maps and briefly describes the Archean[3] granite of the Aspen district of Colorado. This is unconformably below and in direct contact with sediments of upper Cambrian age.

Davis[4] in a general account of a trip through the Colorado Canyon district briefly describes certain features of the pre-Cambrian geology. He calls attention to the extraordinary evenness of the floor of schists with granite dikes (Archean) upon which the Chuar and Unkar terranes (Algonkian) rest. The floor for the Paleozoic strata is somewhat less regular than the floor for the Unkar. In two places the pre-Cambrian rocks rise higher than the basal Tonto (Cambrian) sandstone. The Archean schists beneath the Unkar have a steep and regular slope, indicating uniform resistance to erosion. Where, beneath the Tonto, they show a bench, it is taken to indicate a softer character at this point, probably due to a longer period of pre-Tonto weathering.

[1] Telluride Folio, Colorado, by WHITMAN CROSS: Geol. Atlas of the U. S., No. 57, 1899.

[2] Geology of the Aspen Mining District, Colorado, with Atlas, by J. E. SPURR: Mon. U. S. Geol. Surv., No. 31, 1898, pp. 1–4.

[3] The term Archean is evidently used in the sense of pre-Cambrian.

[4] Notes on the Colorado Canyon District, by W. M. DAVIS: Am. Jour. Sci., 4th ser., Vol. X, 1900, pp. 251–259.

Blake[1] refers to the Archean the thick layers of gneiss forming the southern flank of the Santa Catalina Mountains, Arizona. The gneiss is in flat layers representing beds. A part of it is augen gneiss; other layers are quartzose and seemingly quartzites.

Knight[2] in connection with the discussion of the artesian basins of Wyoming gives a brief description, accompanied by a map, of the geology of the state. Algonkian and Archean rocks are present. The Archean rocks consist mainly of granite, in places cut by dikes of porphyry containing mineral ores, which can be seen in typical exposure at Sherman, Laramie Peak, east of Whalen Canyon, along the Big Horn, Wind River, Gros Ventre, Medicine Bow, Ferris, Seminoe, and Owl Creek ranges, along the Sweetwater River, a few miles northwest of Rawlins, and north of Clark's Fork, in Big Horn county.

The Algonkian rocks are for the first time separated from the Archean. They consist of schists in great profusion, marbles, and quartzites, all cut with dikes of eruptive rocks. They occur in granite basins in unconformity with the Archean, and form important bands in numerous localities. The strike of the series varies from north to northeast and the dip of the strata is seldom less than 65–75°. The thickness of the entire series has not been absolutely measured, but including the eruptive band, which does not form an important part, the maximum thickness in Wyoming is about 20,000 feet. Typical areas have been found in the Black Hills in Wyoming, and occasional outcrops from that place to the Hartville hills — one exposure being east of Lusk, another at Rawhide Butte, and a large one in Whalen Canyon. They also occur at Halleck Canyon, Plumbago Canyon, in the Medicine Bow Mountains, nearly all of the Sierra Madre Mountains, in the Seminoe Mountains and in the Sweetwater mining district of the Wind River range. None of these localities have been examined in detail; but sufficient work has been done to prove that these rocks were at one time sedimentary, and that they have been changed by metamorphism to schists. In the Sweetwater districts the rocks are chiefly schists; but there are many bands of erruptive rock that form dikes which follow the strike of the formation.

[1] Mining in Arizona, by WM. P. BLAKE: published in report of the Governor of Arizona to the Secretary of the Interior, Washington, 1899, p. 142.

[2] A preliminary Report on the Artesian Basins of Wyoming, by WILBUR C. KNIGHT: Wyoming Experiment Station, Bulletin No. 45, 1900. Part on pre-Cambrian, pp. 111–116. With geological map. This is the first geological map of Wyoming that has appeared.

Weed[1] maps and describes the pre-Cambrian rocks in the Fort Benton and Little Belt Mountains quadrangles of Montana.

The Archean rocks are found only in the Little Belt range in the southwestern part of the Fort Benton quadrangle and in the northwestern part of the Little Belt Mountains quadrangle. They are gneisses and schists of various kinds, and of somewhat uncertain origin. They are, in part at least, of igneous origin, and none of them show any traces of sedimentary origin. Their relations to the Algonkian rocks are those of unconformity. The Algonkian rocks are found in the mountain tracts of the Little Belt range, in Castle Mountain, and in the low range crossed by Sixteenmile Creek in the southwest corner of the Little Belt Mountain quadrangle. They are divided into the Neihart quartzite and the Belt formation,[2] both of which are parts of what Mr. Walcott has called the Belt Terrane.

The Neihart quartzite is a hard pink and gray quartzite forming the base of the Belt Terrane for this area. It is found in the vicinity of Neihart in the Little Belt Mountains. Its thickness is about six hundred feet. The Belt formation consists mainly of slaty, siliceous shales, but also contains interbedded limestone and quartzite. Fossils found in this series (in the shales above the formation which Mr. Walcott has named the Newland limestone member of the Belt Terrane), represent the earliest forms of life yet known. Near Neihart the Algonkian period is represented by 4000 feet of beds, while further south and west the thickness is much greater.

Overlying the Algonkian rocks conformably are rocks containing Middle Cambrian fossils. North of Neihart they rest directly on the Archean.

Reconnaissance geological surveys in Alaska and adjacent portions of British Columbia, by United States and Canadian government parties, have shown the basal rock over considerable areas to be a granite, which is provisionally assigned to the Archean.[3] Such granite

[1] Fort Benton and Little Belt Mountains Folios, by WALTER HARVEY WEED: Geol. Atlas of the U. S., Nos. 55 and 56, 1899.

See also Geology of the Little Belt Mountains, Montana: Twentieth Ann. Rept. U. S. Geol Surv., 1898–9, Pt. III, 1900, pp. 278–284.

[2] The Belt formation includes the various lithological members of the Belt Terrane which Mr. Walcott has named the Chamberlin shale, the Newland limestone, the Greyson shale, the Spokane shale, and the Empire shale.

[3] Usually in the sense of pre-Cambrian.

is reported as occurring along the Pelly and Dease Rivers (Dawson[1] and Hayes;[2]) to the west, between the northern base of the St. Elias Mountains on the Yukon River (Hayes[3]); along the Upper Tanana River (Allen[4] and Brooks[5]), which is correlated by Spurr with the granite along the Pelly River; along Fortymile Creek, a tributary of the Yukon near the Canadian-Alaskan boundary (Spurr[6]); forming the core of the Kaiyuh Mountains (described by Dall,[7] referred to Archean by Spurr[8]); possibly forming the core of the Alaska Peninsula and the Aleutian Islands (noted by Dall[9] and Purington,[10] referred to Archean by Spurr[11]).

C. K. Leith.

On Rival Theories of Cosmogony. By the Rev. O. Fisher. *American Journal of Science*, June 1901, Pp. 414–422.

In this article the author has brought the current gaseo-molten hypothesis of the origin of the earth into comparison with the hypothesis of gradual accretion without a molten state recently advanced by Chamberlin, and has endeavored to test the tenability of the newer hypothesis by subjecting some of its fundamental postulates to mathematical and physical inquiries. The author disclaims holding a brief for either hypothesis and well sustains his claim to an impartial attitude.

[1] George M. Dawson: Geological Natural History Survey of Canada, Vol. III, Pt. I, 1887–8, p. 34B.

[2] C. Willard Hayes: Geographic Magazine, Vol. IV, 1892, p. 139.

[3] Loc. cit., p. 139.

[4] Lieutenant H. D. Allen: Expedition to the Copper, Tanana, and Koyukuk Rivers, Senate Documents, Washington, 1897, p. 159.

[5] A. H. Brooks: Twentieth Ann. Rept. U. S. Geol. Surv., Pt. VII, 1900, pp. 460–465.

[6] J. E. Spurr: Eighteenth Ann. Rept. U. S. Geol. Surv., Pt. III, 1898, pp. 134–140.

[7] W. H. Dall: Seventeenth Ann. Rept. U. S. Geol. Surv., Pt. I, 1896, pp. 862, 863.

[8] J. E. Spurr: Twentieth Ann. Rept. U. S. Geol. Surv. Pt. VII, 1900, pp. 235 and 241.

[9] W. H. Dall: Seventeenth Ann. Rept. U. S. Geol. Surv., Pt. I, 1896, p. 135.

[10] C. W. Purington: Manuscript map referred to by Spurr.

[11] J. E. Spurr: Twentieth Ann. Rept. U. S. Geol. Surv. Pt. VII, 1900, pp. 233–235.

He cites at the outset a difficulty, "perhaps more apparent than real," encountered by the newer hypothesis in the sporadic arrangement of the meteoric material which, if like known meteorites, would differ from the existing surface rocks. This difficulty, however, loses much, if not all, of its force when the effects of volcanic action are considered. The hypothesis assumes that the interior heat which arises from compression gives rise to the melting of certain constituents of the rock mass, and that these, previous to eruption, undergo magmatic differentiation into the well-known igneous rocks and probably into others which are but rarely ejected because of their high specific gravity, as the iron-bearing basalt of Disco Island, Greenland, and other extremely basic rocks of the ferro-magnesian type. Volcanic action is assumed to have begun effectively before the growing earth reached the size of the moon and all accretions subsequently made would be more or less invaded and overflown by igneous intrusions and extrusions of differentiated lava. In the closing stages of the earth's growth, the infall of meteoric matter declined gradually to an inappreciable amount, while the volcanic action is thought to have continued with relative vigor for a notable period after the essential cessation of growth, and to have perpetuated itself in less activity down to the present time. If the moon may be taken as an illustration of the prevalence and effectiveness of surface vulcanism in a body one eightieth of the earth's mass, it does not seem violent to suppose that the original meteoric matter of the earth would be deeply buried under surface lava flows and tuffs in the closing stages of its growth. Recent studies in the Lake Superior region, in Scandinavia, and in Lapland seem to concur in showing that the oldest known rocks consist of such lava flows and pyroclastic layers associated with some small amounts of ordinary clastic material, all mashed into schistosity. Into these schists, the great granitic series were intruded. Under the newer hypothesis these intrusions are to be regarded as merely a continuation of the earlier active vulcanism which was then more largely basic, but which had now, in the progress of magmatic differentiation, attained a dominant acidic character, perhaps as the partial complement of the earlier basic flows of the schist series or of the later basic flows of the Algonkian. The "fundamental gneiss" does not, therefore, appear, in the light of these recent studies, to be *fundamental*, nor does the "basement complex" appear to be *basal*. These recent investigations seem to bring the Archean series into almost

ideal conformity with the accretion hypothesis, if under that hypothesis the process of accretion is conceived as dying away gradually by a transition into a stage of dominant vulcanism, which in turn gradually passes into the present phase of dominant aqueous activity. On the other hand, progressive investigation seems more than ever to give negative results in the line of the discovery of "the original crust" of the hypothetical molten stage, and the survival of the older hypothesis will perhaps require the recognition of a dominant eruptive stage similar to that postulated by the newer hypothesis, to which all or most of the Archean rocks are to be referred. In the light of these late Archean investigations, the difficulties of the old hypothesis seem at least as great as those of the new, for the old hypothesis must account for the non-appearance or scant appearance of "the original crust," while the new must account for the non-appearance or scant appearance of the supposed highly basic, magnesian, iron-bearing meteoric matter. The new hypothesis has the advantage of having theoretically postulated in advance what field studies are now bringing into recognition in spite of prepossessions inherited from the older view.

Passing the problem of superficial constitution as not necessarily serious, Fisher justly regards the increase of internal density and high internal temperature as incontestable facts of radical importance, and inquires how these facts may be accounted for on the meteoric theory. He assumes the average density of the meteoric matter to be nearly that of average surface rock, 2.75, and adds that "if this is too low, the arguments based upon it will not be affected in any great degree." Fisher feels tolerably certain that the law of internal density is fairly represented by Laplace's law, which is that "the increase of the square of the density varies as the increase of the pressure." In the case of a slow growth by solid accretion, the internal density must be mainly referred to compression. If, however, the specific gravity of the original meteoric material be taken at some figure between 3.5 and 4, as derived from known meteorites (Farrington's figure in 3.69), the amount of compression is appreciably less than on the assumption of 2.75 made in the computations. Fisher finds that at a depth of 400 miles, where by Laplace's law the density should be 3.88 the compressibility would be 1.4021×10^{-6}. "This may be looked upon as a small compressibility, seeing that the compressibility of water similarly measured is 4.78×10^{-5} or nearly forty times as great." The linear

dimensions would be reduced about one tenth. "At the center the compressibility similarly measured would be very small, viz., 2.5×10^{-7}, while the condensation would be large, viz., 0.744."

In the absence of direct measurements on the compressibility of rocks, the author computes its value from the values of Young's modulus and the modulus of rigidity which have been obtained in some instances, and compares the result with the theoretical compressibility of surface rocks deduced from Laplace's law. Respecting the results, he remarks that "it is certainly not a little remarkable how closely this value ranges with those found by experiment. It is of the same order of magnitude but rather smaller than the average." He adds:

> We find here a somewhat strong presumption in favor of the view that the earth consists throughout of matter not very dissimilar from what we know at the surface, and that the internal densities are due rather to condensation than to the presence of heavier substances such as metals. But it is not a proof of this.

Respecting the alternative view that the greater density toward the center is due to heavy metals, Fisher says:

> We may probably dismiss the supposition that these all fell in first, and only regard them as segregated from a uniform mass of some kind, and having gravitated towards the center. This implies a condition of liquidity. If the materials were solid this separation could not have occurred. Now the only force that we know of that could cause the denser materials to move by a kind of convection towards the center is gravity; and in a solid gravity would not have that effect. Moreover, it must not be forgotten that gravity continually diminishes as we go deeper into the earth, and that at the center bodies have actually no weight. It is greatest at the surface, and if not competent to segregate downwards the heavy particles of a rock at the surface, which we know it is not, still less could it have that effect near the earth's center.
>
> Neither can we attribute this segregation to pressure; for pressures act equally upon the surface of heavy or light materials. If we had a layer of mixed shot and sand, no steady pressure laid upon it would force the shot to the bottom and bring the sand to the top.
>
> It seems, therefore, that the view that the denser materials in the interior consist of heavy metals necessitates a condition of liquidity of the whole, which accords more readily with the nebular than with the meteoric theory of its origin. For we may imagine that in a nebular mass cooling from the exterior, the first change from a nebulous or gaseous state would be the formation of a rain of condensed particles falling downwards, which would continue until the whole mass became liquid, and thus the heavier elements would begin to

collect towards the center. In this case the highest possible interior temperature would be that at which the gaseous first assumed the liquid condition under the pressure at the depth.

Paradoxical as it appears, it is therefore possible that the temperature in the interior may have been rendered higher by a conglomeration of cold solid meteorites than by the cooling of a nebula.

We have no means of judging whether the meteorites would come in rapidly or slowly, but in either case if we take no account of the heat arising from impact, the amount produced by condensation would be the same; the only difference in the two cases being that it would be generated in a less or greater time. In the meanwhile a covering of a badly conducting material would concurrently accumulate, preventing the rapid escape of this heat, and at the same time increasing the pressure, the compression, and the heat.

To form an idea of the temperature which would be produced by the condensation of matter of surface density to the density now existing at any given depth within the earth, not taking into account its diffusion by conduction or otherwise, we require to know the work which has been expended upon it. Now we can estimate this in the following manner. Conceive the earth to have been built up of meteorites falling in, so that shell after shell accumulated until the globe attained its present size. Then, fixing the attention upon a particular unit volume, say a cubic foot, of the substance, and omitting atmospheric pressure, it would successively be subject to every degree of pressure from zero, when the shell of which it formed a part was not covered up, until the present pressure was reached, when it was buried to the depth at which it now lies. If then we know the relation between the pressure and the compression at every depth at the present moment, it will give us the relation between the pressure and the compression which that particular volume has obeyed during the course of ages; that is to say, we can judge how much compression any given pressure would have produced in the substance under the conditions involved.

Laplace's law of density being based upon the assumption that the increase of pressure within the earth is proportional to the increase of the square of the density, in terms of a pressure of one pound upon the square foot, this leads to the result, that the pressure at the depth where the density is p is equal to $5.9 \times 10^7 \ (p^2 - s^2)$ [where s=density of surface rock and p= density of rock at the depth under consideration].

If we accept Laplace's law, this expresses a fact, whether the increase of density is due to condensation by pressure or to increased density in the intrinsic nature of the matter. But if we assume that the increase of density is caused solely by the pressure, then the above relation gives the amount of pressure which would reduce matter of density s to matter of density p under circumstances existing within the earth. It will therefore remain true if the

matter changes its state from solid to liquid, and from liquid to gas. If, for instance, we wished to apply a pressure which would reduce surface rock to the density 3, it ought to be $5.9 \times 10^7 (9-2.75^2) = 8.481 \times 10^7$ pounds per square foot, supposing no heat be allowed to escape. If the experiment could be made, it would afford a test of the truth or otherwise of the present hypothesis.

When we know the relation between the pressure and the condensation which it would produce, it is feasible to estimate the heat which would be generated, and also the temperature, provided we assume the specific heat of the substance, which for surface rock has been determined. For instance, at the depth of 0.1 of the radius, or about 400 miles deep, where the density would be 3.88, the temperature produced by condensation would be 1.2608×10^5 Fahr., or 7.0044×10^4 Cent. [70,044°], while at the center the figures would reach 2.7756×10^6 Fahr., or 1.0242×10^6 Cent. [1,024,200°]. It seems at any rate that the meteoric theory would not fall short of accounting for temperatures as high as might be desired. It must at the same time be remembered that much of this heat would not be called into existence until the substance into which it was, as it were, being squeezed, had already been deeply buried under a badly conducting covering, so that the escape of heat would not take place as fast as it was generated, as would probably be the case with heat generated at the suface by impacts. Thus the hypothesis that the present high internal temperatures are due to compression seems quite admissible.

We may compare the above named temperatures with some that are known. Acheson, for instance, obtains 6500° Fahr. in his Carborundum electric furnace, and 3300° Fahr. has been obtained by the oxyhydrogen flame. These temperatures are contemptible compared with those mentioned above. The Hon. Clarence King, prolonging Dr. Barus' line for the melting point of diabase (which is 1170° C. at the earth's surface) to the earth's center, gives the temperature 76000° Cent., which is of the same order of magnitude as condensation would produce at only 400 miles depth.

Fisher considers the bearing of the temperature of lava as determined by Bartoli at Etna (1060°C. or 1932° F.) on the question, and finds that the theoretical depth at which this lava temperature would be produced by condensation would be about forty-three milės. The same temperature would be reached at the accepted gradient of 1° F. for sixty feet in about twenty-two miles.

It seems then that the hypothesis, that the internal densities are due to the condensation of matter of surface density, will not account for a temperature gradient originally as high as at present. [The computed gradient corresponds pretty nearly with the low gradient found at the Calumet and Hecla

mine.] Nevertheless the above observations upon the temperature of lava, and the comparatively small depth, forty miles, at which condensation of rock would be capable of producing it, together with the small amount of condensation necessary, viz., 0.041, render it quite probable that fusion may have ensued in the deep interior without the necessity of a greater amount of condensation than such materials might be supposed capable of under the enormous pressure to which they would be subjected, even allowing for the increase of the melting point under pressure. . . . . It will be noticed that a compression less than would be requisite of itself to produce the necessary density would be sufficient to produce the requisite temperature for fusion. But while any stratum was cooling by the conduction upwards of its own heat of compression, it would be receiving heat from regions below, where, so long as condensation was going on, the materials would grow hotter and hotter. It seems therefore possible that the upper layers, forming what we call the crust of the earth, may have received sufficient heat supplied from below to render the temperature gradient at the present time higher than it was originally, and that even those Archean rocks, which are by many thought to have been once melted, do not necessarily prove that the earth was not built of cold meteorites.

The presence of water upon the earth has to be accounted for, and the meteoric theory does not easily lend itself for this purpose. Not only is water present in the ocean and in the atmosphere, but also in a state of solution in the interior, as is testified by the enormous amount of steam emitted by volcanoes, and by cooling lava. It does not seem possible that molten rock can imbibe water from without, because it would be driven away instead of attracted, since the superficial tension of a substance diminishes as the temperature rises.

The problem of accounting for the vast quantities of steam emitted by lavas is shared by both theories. Under the hypothesis of a molten earth, steam must have been absorbed either in the original molten state or during the later stages of segregation and ascent, neither of which alternatives seems to be free from difficulties. Under the meteoric hypothesis, it is assumed that hydrogen, carbon dioxide, carbon monoxide, and nitrogen were carried into the whole body of the earth by the infalling matter in some such degree as they are brought to the surface now by meteorites, and that these gases, joined with oxygen derived from the partial reduction of the oxides of the meteoric matter when subjected to the high temperatures of the interior, were extruded by volcanic and similar means and gave rise to the ocean and atmosphere. Under this hypothesis the volcanic gases are regarded as mainly original and as merely lingering expressions

of the process that was much more intense during the later stages of the earth's growth. Cosmic accretions, which may be a notable factor, would be equally functions of either hypothesis so far as the maintenance of the atmosphere and ocean is concerned.

In submitting the newer hypothesis to the test of physical principles and mathematical computations, Fisher has done it an honor that is sincerely appreciated. By showing that its more radical features lie within the tenable limits of theory, he has helped to give it a place as a genuine working hypothesis; and as such it may have some stimulating value as a competitor of the gaseous and molten theory which has practically monopolized geological opinion for the past century.

T. C. C.

Glacial Sculpture of the Bighorn Mountains, Wyoming. By FRANÇOIS E. MATTHES. Extract from the Twenty-first Annual Report of the United States Geological Survey, 1899–1900. Washington, 1900.

Glaciation affected the crest of the Bighorn Mountains for more than thirty miles. The range was not covered by a continuous ice cap, and glaciation was confined to valleys. The mountains abound in well developed, elongate, valley-like cirques, which have been but little altered by postglacial changes. The author indorses Johnson's view of the origin of cirques, namely, that they are due to sharply localized and abnormally vigorous weathering, by rapid alternation of freezing and thawing at the exposed bottoms of *bergschrunds.* Mr. Matthes' studies have led him to the conclusion that the location of the *bergschrunds* in any valley is determined by the depth of the névé.

The longest glacier of the Bighorn Mountains is said to have been eighteen miles in length, its terminus reaching down to an altitude of less than 7000 feet. The thickness of the larger glaciers was 1000 to 1500 feet. Small glaciers still exist in the highest part of the range, a little below 44° 30′, at an altitude of about 12,000 feet.

In addition to the account of the effects of the active valley glaciers on topography, the author discusses the effect of inactive snow and névé. The névé effects are described under the term "nivation," and the "nivated" valleys are distinguished from the glaciated valleys. This, so far as we are aware, is the first attempt to analyze the effects of inactive ice and névé on topography. The discussion even involves

the effects of snow banks. The thickness of the névé fields which did not become glaciers is estimated to have been 100 to 150 feet, and the conclusion is reached that, on a grade of about 12 per cent., the névé must attain the thickness of at least 125 feet in order to have motion.

Certain phases of the problem of glacial motion are touched, and the conclusion reached that the cause of glacial motion is to be sought in the weight of the ice mass, and that it is independent of the temperature of the air. No attempt is made, however, to decide the real nature of glacial motion, or what processes are involved in it.

R. D. S.

Annual Report of the Board of Regents of the Smithsonian Institution, showing the Operations, Expenditures, and Condition of the Institution for the year ending June 30, 1899.

In the appendix accompanying the official report of the governing bodies and the secretary of the Smithsonian Institution, a complementary number of geological articles are introduced. These are, for the most part, republications, and include "On Lord Kelvin's Address on the Age of the Earth as an Abode Fitted for Life," by T. C. Chamberlin; "An Estimate of the Geological Age of the Earth," by J. Joly; "The Petrified Forests of Arizona," by Lester F. Ward; "Present Conditions of the Floor of the Ocean; Evolution of the Continental and Oceanic Areas," by Sir John Murray; "The Truth About the Mammoth," by Frederic A. Lucas; "Mammoth Ivory," by R. Lydekker; and "Review of the Evidence Relating to Auriferous Gravel Man in California," by William H. Holmes. Several of the physical and biological articles, and those relating to general aspects of science, also possess points of interest to geologists.

C.

Recent Publications

—Becker, George F. Conditions Requisite to our Success in the Philippine Islands. An address delivered before the American Geographical Society, February 20, 1901. [Reprinted from Bull. of the Am. Geog. Soc., April 1901.]

Report on the Geology of the Philippine Islands. Followed by a version of Ueber Tertiäre Fossilien von den Philippinen (1895) by K Martin. [Extract from the Twenty-first Annual Report of the U. S. Geological Survey, 1899–1900. Part III—General Geology, Ore and Phosphate Deposits, Philippines.] Washington, 1901.

—Collie, George Lucius. Wisconsin Shore of Lake Superior. [Bull. of the Geol. Soc. of Am., Vol. XII, pp. 197–216.] Rochester, April 1901.

—Davis, W. M. An Excursion in Bosnia, Hercegovina, and Dalmatia. [From Bulletin, Vol. III, No. 2, Geog. Soc. of Philadelphia.]

An Excursion to the Grand Canyon of the Colorado. [Bulletin of the Museum of Comparative Zoölogy at Harvard College, Vol. XXXVIII. Geological Series, Vol. V, No. 4; with two plates.] Cambridge, Mass., May 1901.

The Geographical Cycle. [Paper read at the Seventh International Geographical Congress of Berlin in 1899.] Berlin, 1900.

—Dorsey, George A. Archæological Investigations on the Island of La Plata, Ecuador. [Field Columbian Museum, Publication 56; Anthropological Series, Vol. II, No. 5.] Chicago, April 1901.

—Dorsey, George A and H. R. Voth. The Oraibi Soyal Ceremony; The Stanley McCormick Hopi Expedition. [Field Columbian Museum, Publication 55; Anthropological Series, Vol. III, No. 1.] Chicago, March 1901.

—Dumble, E. T. I, Cretaceous of Obispo Canyon, Sonora, Mexico. [Reprinted from the Transactions of the Texas Academy of Sciences, Vol. IV, Part I, 1900.] II, Occurrence of Oyster Shells in Volcanic Deposits in Sonora, Mexico.

Geology of the Beaumont Oil Field.

Natural Coke of the Santa Clara Coal-Field, Sonora, Mexico. [Transactions of the American Institute of Mining Engineers, California Meeting, September 1899.]

The Iron Ores of East Texas.

The Oil Deposits of Texas.

—ELLIOT, D. G. A List of the Land and Sea Mammals of North America North of Mexico. [Field Columbian Museum, Publication 57; Zoölogical Series, Vol. II, No. 2.] Chicago, June 1901.

A List of Mammals obtained by Thaddeus Surber, in North and South Carolina, Georgia, and Florida. [Field Columbian Museum, Publication 58; Zoölogical Series, Vol. III, No. 4.] Chicago, June 1901.

The Caribou of the Kenai Peninsula, Alaska. [Field Columbian Museum, Publication 59; Zoölogical Series, Vol. III, No. 5.] Chicago, July 1901.

—FISHER, REV. O. On Rival Theories of Cosmogony. [From the American Journal of Science, Vol. XI, June 1901.]

—India, Geological Survey of. General Report for the Year ending March 31, 1901. C. L. Griesbach, Director. Calcutta, 1901.

—New Jersey, Geological Survey of. Annual Report of the State Geologist for the Year 1900. Trenton, N. J., 1901.

—NUTTING, C. C. The Hydroids of the Woods Hole Region. [Extracted from U. S. Fish Commission Bulletin for 1899, pp. 325–386. Date of publication, June 8, 1901.] Washington, 1901.

—OLDHAM, R. D. Beach Formation in the Thirlmere Reservoir. [Abstract of a paper read before the British Association, Bradford, 1900.]

—Øyen, P. A. Variations of Norwegian Glaciers. [Separataftryk af "Nyt f. Naturvidenskab," B. 39, H. 1. Kr. ania, 1901.] Christiania, April 1901.

—RABOT, CHARLES. Les Variations des Longueur Des Glaciers dans les Régions Artiques et Boréales. [Extrait des Archives des sciences physiques et naturelles Années 1899 et 1900.] Genéve et Bale, 1900.

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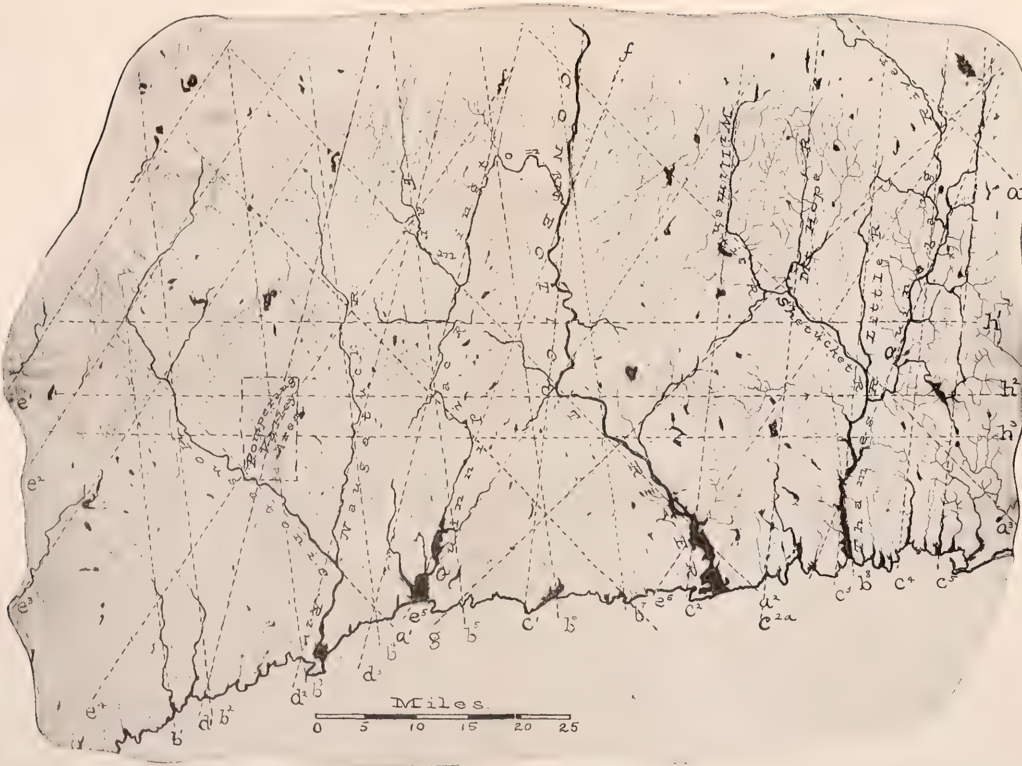
—SHIMEK, B. The Loess of Iowa City and Vicinity. Iowa Pteridophyta (Con.). Addenda to the Flora of Lyon County. [Excerpt from the Bulletin of the Laboratories of Natural History, State University of Iowa, Vol. V, No. 2, pp. 195-216.] May 1901.



RIVER MAP OF CONNECTICUT

(Reduced from the two-sheet map of Connecticut by the U. S. Geological Survey)

The dotted lines indicate the prominent "trough lines," which trend as follows:

a^1, a^2, etc., N. 44° W.	c^1, c^2, etc., N. 5° E.	e^1, e^2, etc., N. 33° E.	g, N. 48° E.
b^1, b^2, etc., N. 5° W.	d^1, d^2, etc., N. 15° E.	f, N. 20° E.	h^1, h^2, etc., N. 90° E.W.

THE

JOURNAL OF GEOLOGY

SEPTEMBER-OCTOBER, 1901

THE RIVER SYSTEM OF CONNECTICUT[1]

THE tendency of the modern school of physiographers seems to be to ascribe little importance to geological structure planes as a factor in determining the position and the orientation of water courses. In an earlier period greater attention seems to have been accorded to this condition, and quite apart from the purely theoretical conceptions of the closet geologists many valuable observations were placed upon record. Th. Kjerulf, the former Director of the Geological Survey of Norway, remarked the regularity in the arrangement of fjords, streams, and valleys as represented upon the map of Norway, and from this was led to believe that their directions corresponded to the faults in a system of dislocations. Daubrée[2] has furnished many examples of regular networks of stream channels which resemble the network produced by a number of intersecting series of parallel joint planes (*réseaux réguliers de cassures*), and the explanation of this correspondence he believed to be a causal one, the planes of separation, or jointing, being locally gaping where the streams adhere to the joint direction, but closed where they have been diverted from the course of the joint. Van Hise[3] has in a similiar way explained the zigzags of

[1] Published with the permission of the Director of the U. S. Geological Survey.

[2] DAUBRÉE: Géologie Experimentale. Paris, 1879, p. 361.

[3] VAN HISE: Trans. Wis. Acad. Sci., etc., Vol. X., pp. 556–560, 1895.

the small streams which enter the Wisconsin River at the "Dells" as due to a system of joints induced by the gentle folding of the rocks. That a more or less uniform system of joints exists in the rocks almost throughout the state of Wisconsin has been shown by Buckley's observations.[1]

So far as the writer is aware, the only detailed studies that have been made establishing the definite relationship of the stream channels of a region to its system of joints or faults, are those of Brögger[2] in the Langesund-Skien and Christiania regions of southern Norway, and that of the writer[3] in the Pomperaug Valley region of Connecticut. Of the elaborately faulted region which Brögger has studied, he states:

It is not exaggerated when to my own astonishment I must state, as the final result of my observations in this region, that almost every valley, every cleft, is formed along a fault fissure. . . . . The significance of the faults for the formation of the valley straits is thus as profound as possible within the stretch of land described, since almost every cliff, every vale, every bay has been formed upon a line of dislocation; indeed the presence of clefts was for me, at the last, the surest index for the discovery of dislocations.[4] [Translation.]

Review of the geological structure of the Pomperaug Valley area of Connecticut.—Regarding the Connecticut area to which reference is made, it will be necessary here to review the study in order to make clear the generalizations with which this paper is especially concerned. It is now well known that the several areas of Newark rocks of the eastern United States are complexly faulted, and the many common structural peculiarities of the several isolated areas give rise to the belief that the forces which have produced the dislocations have affected, not the Newark rocks alone, but the larger region of which they are parts—the Piedmont plateau of the eastern United States.[5]

[1] BUCKLEY: Bull. 4, Geol and Nat. Hist. Surv. Wis., pp. 450–460, 1898.

[2] BRÖGGER: Nyt Magazin for Naturvidenskaberne, Vol. XXVIII, pp. 253–419, 1884. *Ibid.*, Vol. XXX, pp. 99–231, 1886.

[3] HOBBS: Twenty-first Ann. Rept. U. S. Geol. Surv., Pt. III, 1901, pp. 1–162.

[4] Op. cit., pp. 34, 342.

[5] Cf. DAVIS: The Triassic Formation of Connecticut, Seventh Ann. Rept. U. S. Geol. Surv., 1888, pp. 481–490.

The detailed study of the Pomperaug Valley area has developed the fact that a complex system made up of intersecting series of parallel nearly vertical joints and faults there divides the crust into a large number of orographic blocks, the smaller of which have dimensions of less than one hundred paces. The different throws along the numerous faults bounding these blocks have brought about a structure not unlike that of a mosaic from which the supporting base has been lowered and the individual stones been displaced by different amounts due to the inequalities of their lateral support. For the area as a whole, the joints and corresponding faults are embraced mainly in four series, the individual members in which trend N. ± 34° W., N. ± 55° E., N. ± 5° W., and N. ± 15 E. Series of faults less common for the area as a whole, but several of them numerous enough in its southern portions, have directions N. ± 33° E., N. ± 44° W., N. ± 61° W., N. ± 90° E. W., N. ± 20° E., and N. ± 25° W., the order being approximately that of frequency of occurrence. Of the more common series, those trending N. ± 55° E. and N. ± 34° W. are nearly normal to one another, as would be true of a pair of joint planes, but the larger throws within the region seem generally to have taken place along one of these planes (N. ± 55° E.) and one of the other prevailing directions (N. ± 5° W.). Aside from the regularity in direction observed to characterize the numerous faults and bring them into a number of parallel series, those faults of the same order of displacement are observed to be spaced also with noteworthy regularity. The smallest of the orographic blocks which could be measured, for convenience called the "unit" blocks, were found to be quite generally about 50 paces (150 feet) along the direction N. ± 55°E., and 100 paces (300 feet) along the direction N. ± 5° W.—the equivalent of two rhombic prisms in contact along one side. The larger, or "composite" blocks, which are of various orders of magnitude, are made up of the "unit" blocks and bordered by displacements of a higher order—greater throw. The fault intervals in the several series, and hence the shapes of the orographic blocks, are found to be closely related to the directions

of the prevailing and rarer fault series in a manner which is made clear by the diagram of Fig. 1. In this figure the shape of the unit orographic block—and of many composite blocks of several orders as well—is shown by the black and also by the stippled area. Two of the prevailing fault directions, N. ± 15° E. and N. ± 34° W. correspond to the longer and the shorter diagonals respectively of this unit block. The fault direction N. ± 33° E., which is the most common of those occurring in the southern Pomperaug area, corresponds closely to the longer diagonal of three unit blocks in contact along their longer side. Another of the series of faults characteristic of the same southern area and trending N. ± 20° E., corresponds to the longer diagonal of six unit blocks, two composite blocks like those just described placed in contact along their longer sides. The remaining directions of faults observed in the area are respectively the shorter diagonals of composite blocks three units long and two wide, four long and six wide, four long and seven wide, and two long and seven wide; though clearly in these latter instances, the relationships indicated in the diagram are less significant owing to the more complex nature of the composite blocks of which the fault directions are the diagonals. For a more important indication of the same relationship, which is observed in the actual composite blocks of the area studied, the reader must be referred to the original report.[1]

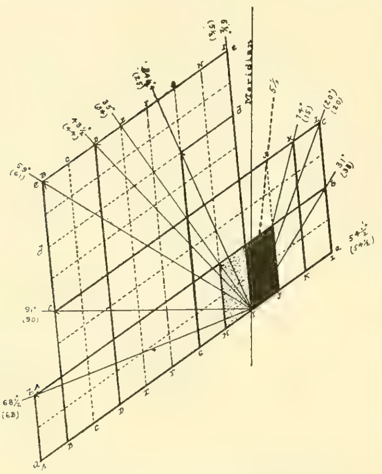


FIG. 1.—Diagram to illustrate the relationships existing between the shape of the "unit" orographic blocks and the directions of the fault series.

For the area in question the conclusion has been drawn that the earth's crust has been here subjected to compressive stresses,

[1] Loc. cit. pp. 117–120.

the resultant of which acted in a direction normal to the axis of Green Mountain folding (N. ± 80° W.), stresses which were relieved by dislocation along the planes of maximum shear, approximately 45° to either side of the direction of pressure, *i. e.*, S. ± 55° W. (N. ± 55° E.) and N. ± 34° W. The remaining common directions of fault planes (N. ± 15° E. and N. ± 5° W.) could be explained by a subsequent development of compressive stress acting along the initial direction; for in a region containing planes of separation at 45° to the direction of pressure, there would be a resolution of the stress into components acting along the planes of separation and along that diagonal of the blocks which is nearly normal to the pressure. The direction N. ± 15° E. corresponds to this diagonal of the joint block already formed, and the remaining direction N. ± 5° W. is the corresponding diagonal of two such blocks in contact. To explain these latter dislocations upon the same principle, it must be assumed that, owing to differences between the alternate joint planes of the same series, these double joint blocks acted to some extent as units. The fault directions characteristic especially of the southern portion of the area and disclosing such intimate relationships to the four generally prevalent ones, might be explained either by assuming that in the later compression of the jointed area composite blocks of different shapes, because composed of a different number or different arrangement of unit blocks, acted as units (whether due to the greater perfection of their bounding fault planes over intermediate ones, to the partial closing or healing of the intermediate faults, or to some other cause). In this case the maximum shear would be along the diagonal of the composite blocks, as would be the case in the unit blocks themselves, and it is shown in the report under review that these directions do correspond, *not only in direction, but also in position* with the diagonals of important composite blocks of the area. Under certain conditions, which may or may not have obtained in the area, planes of dislocation having the same directions might have been produced through the depression of the composite blocks subsequent to the jointing of the

area, since in this case also the tendency would be for blocks to rupture along the diagonals.

The oriented drainage of the Pomperaug Valley.—With this brief summary of the geological structure within the Pomperaug Valley area we may consider its drainage. It was found in studying the area that the streams, large and small, for considerable distances adhere with great fidelity to the directions of some of the prevailing faults, and that in many cases after being diverted from them, it was noted that they had returned persistently to the old direction. This correspondence of drainage lines to geological structure planes is far too close to be accidental. The four prevailing fault series diverge from their nearest neighbors at angles of about 39°, 20°, 29°, and 92°. A difference in angle between a fault direction and the general direction of a stream course equivalent to 7°, or about one third the smallest difference of angle between neighboring fault directions, would represent a divergence of one in eight, which would hardly be accepted by the eye as an indication of parallelism. It is not to be expected that the actual course of a stream will now be coincident with or even absolutely parallel to any fault direction, for there have unquestionably been many local conditions which have produced larger or smaller migrations of the river channels. Their general direction has, however, it would seem, been maintained despite the minor accidents which have marked their life-histories, and even under so revolutionary a change as complete reversal of drainage.

It was further shown in the investigation under review, that in the walls of crystalline rocks surrounding the Newark beds in the Pomperaug basin, the same adhesion of the water courses to the direction of the observed faults (extended) could be determined. It was hardly to be expected that these peculiarities would cease to be observable so soon as the immediate vicinity of the Newark basin was left behind, if it be indeed true that the dislocation of the area is due to a compression of the general region in which this area of Newark rocks and the much larger one of the Connecticut valley are included. Owing, however,

to the absence over the greater part of the surrounding area of widely different rocks in thin beds, the difficulties of locating fault planes are almost infinitely increased; and, indeed, except under especially fortuitous conditions they elude observation. Having established, however, a relationship in one area, the problem is before us to determine whether the river system of the larger area of Connecticut exhibits any indication of the existence of rectilinear directions more or less persistent embraced in a network of parallel series like that of the Pomperaug Valley; or, if this be not true, whether any other persistent and recurrent directions can be observed. It will be further of special interest if such a system affords indication of a regular space-interval between such parallel lines of drainage.

The oriented drainage of the Shepaug River.— In prosecuting our inquiry regarding the orientation of the drainage lines of Connecticut, the valley of the Shepaug River (its southern portion) was first examined, since this basin immediately adjoins to the west that of the Pomperaug. The diagram of this river traced from the atlas sheet of the map of Connecticut, prepared by the topographic corps of the United States Geological Survey (Fig. 2), affords clear evidence that the geological structure planes have here played an important part in giving direction to the river's channels. The dotted lines of the figure show the inferred approximate positions of fault planes whose course the river has adopted. The most marked adhesion of the river or its

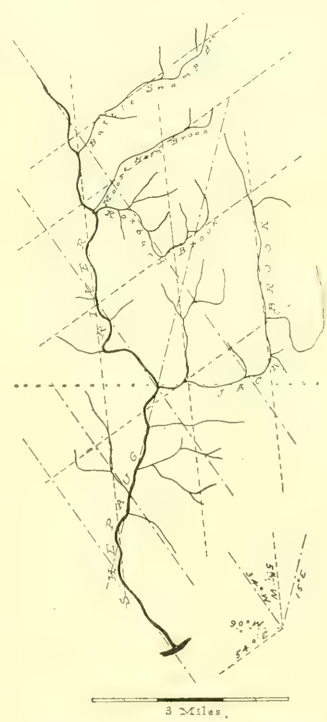
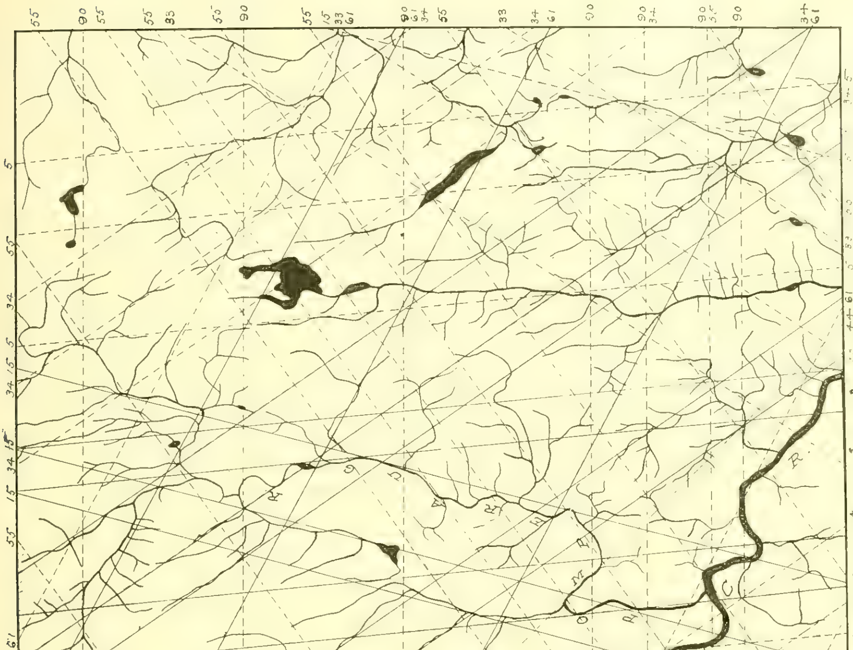


FIG. 2.— Diagram to show the relationship of drainage lines in the basin of the Shepaug River to the prevalent fault and joint lines of the neighboring Pomperaug basin.

branches to any given direction is very closely the direction N. 5° W., as shown by the upper course (in the diagram) of the trunk stream, as well as by the upper course of Jack Brook, its main eastern tributary, and by the small intermediate branch of the latter. These three channels are not only evenly spaced, but to the southward their extensions correspond in position with the southerly trending elements of great elbows of the Housatonic (see Plate II). After receiving the waters of Jack Brook, the Shepaug flows for nearly three miles in the direction S. ± 15° W. (N. ± 15° E.), another of the four prevailing fault directions observed in the Pomperaug Valley. Later it flows S. ± 34° E. (N. ± 34° W), while several tributaries flow along this direction and S. ± 55° W. (N. ± 55° E.), the two remaining of the four prevalent fault directions of the Pomperaug Valley.

The oriented drainage within the area surrounding the Pomperaug Valley.— In the map of Plate II, a larger area, of which the Pomperaug Valley is the center, has been considered. Upon this map, traced from the United States Geological Survey atlas sheets, which are on a scale of one inch to the mile, the full straight lines represent observed faults (extended), and the dotted lines the inferred approximate position of faults. It has, of course, been necessary to omit all but a few of the numerous faults which were observed in the Pomperaug Valley area. The figures on the margin of the map indicate the directions (in degrees) either to the east or west of north of the trough or fault lines which emerge near them. With the greater complexity of this map and the larger number of fault directions represented, relationships are not at once so apparent as in Fig. 2, which upon a reduced scale is here included. Special attention is directed, however, to the fact that the Housatonic itself, which after flowing about three miles in a direction S. ± 5° E. (N. ± 5° W.), assumes the direction S. ± 61° E. (N. ± 61° W.) at first in a nearly straight channel for three miles, and then in a zigzag course for eight miles more. Many interesting peculiarities will be noticed in the orientation of the smaller streams shown upon this map; as, for example, along the N. ± 55° E.

JOUR. GEOL., Vol. IX, No. 6 Plate II



RIVER MAP OF THE AREA SURROUNDING THE POMPERAUG VALLEY

The full lines are observed faults of the Pomperaug Valley area (extended); the dotted lines are "trough lines" (inferred approximate positions of joint or fault planes); the figures on the margin give the angle in degrees to the east or west of the meridian of the "trough lines" which pass near them.

line which approximates to a diagonal of the map, along the N. $\pm$ 33° E. line which meets the lower margin of the map near where the Housatonic meets it, etc. It will hardly escape notice, also, that the most marked lines in each series are spaced with considerable regularity, and if one space is wider than the others, it is often so much wider as to suggest that the space-interval is a multiple of the space which has been regarded temporarily as the unit.

The river system of Connecticut.— An examination of the larger area approximately coëxtensive with that of the state of Connecticut has been made by use of the "two-sheet map of Connecticut," on a scale of one half inch to the mile, prepared by the United States Geological Survey Those lines and characters of this map, such as topography and culture, with which we are not now concerned and which would obscure the relationships sought, were eliminated by preparing a careful tracing of all the streams and their minor branches. Upon this map tracing (about six feet long by four wide) approximately rectilinear stretches of river channel, and especially the stretches of neighboring streams which hold approximately to the same line, were sought. If these directions were found to agree closely with any of the fault directions observed in the Pomperaug basin, dotted lines were drawn following those directions and coinciding as closely as possible with the river courses. If such an observed direction was found not to coincide closely with any of the fault directions determined, a direction was sought which would approximate most closely to it, and a similar dotted line with this direction drawn along the course of the river. The term "trough lines" used to designate these lines, need for the present be given no further signification than lines so favored by nature that the waters of the region have been induced to adopt them for their channels over longer or shorter distances. On a map of this scale the trough lines, if rectilinear, should be slightly curved, but inasmuch as the present river courses, because of the many accidents of their history, can only roughly approximate to the direction initially given them, it would be an

over-refinement to introduce a correction of this nature, and they are, therefore, left straight. When all important trough lines had been thus represented, the map was reduced by photography and the etching of Plate I produced after the important rivers had been made a little heavier in order that their course might be apparent. These details of the study have been noted because the dangers of introducing the personal element while drawing the course of a river with any theory of its orientation in mind are very great. The map conveys a wrong impression, therefore, chiefly in its slightly exaggerating the volume of certain streams which it was necessary to draw with heavier lines in order that their correspondences might be apparent.

The first trough lines to impress the observer are those designated a_1, a_2, a_3, a_4, upon the map, lines which trend approximately N. 44° W., and which include the lower reaches of the Housatonic, of the Connecticut below Middletown, of the lower Willimantic and the Shetucket, and a stretch of the Quinebaug. A less-marked trough line between a_1 and a_2, would include important bends of the Naugatuck and Quinnipiac rivers. The sharp bend of the Connecticut River at Springfield and Patchoug River, tributary to the Quinebaug, may indicate the course of another trough line in this series. Most noteworthy of all lines in this series, however, is a_2, since the lower stretch of the Connecticut (some twenty-five miles long) is continued in the zigzag Sebethe River, so as almost to connect with the stretch of the Farmington River above its sharpest bend at Farmington. The direction of the lower stretch of the Connecticut is of especial interest because the river at Middletown deserts the softer Newark sediments to flow across the crystalline uplands, a peculiarity which has been explained by Professor Davis[1] through conformable superimposition, the stream being supposed powerful enough to maintain an initial course along this direction during the rise of the uplands, at which time the harder gneisses were discovered. The same hypothesis has been offered by Kümmel[2] to

[1] DAVIS: The Triassic Formation of Connecticut, Eighteenth Ann. Rep. U. S. Geol. Surv., Pt. II, 1898, p. 165.

[2] KÜMMEL: Some Rivers of Connecticut, JOUR. GEOL., Vol. I, p. 379, 1893.

explain the lower course of the Housatonic, which similarly deserts the limestone to cross the uplands. The presence of important structure planes in these positions would, in the view of the writer, afford the simpler explanation. It will be noted here that there is considerable uniformity in the spacing of the trough lines of this series, especially a_2, a_3, a_4.

The next most striking series of trough lines is indicated in the course of the Connecticut from Springfield to Hartford (c_1), a distance of twenty-six miles; of the Willimantic (c_2); of the Mt. Hope (c_{2a}); the Little (c_3); and a long stretch of the Quinebaug (c_4). The direction of these trough lines is about N. 5° E., though this is not one of those observed to characterize the faults in the Pomperaug Valley area. Again, the spacing of these trough lines is quite regular if we regard the space between the Connecticut and the Willimantic as a double interval. More striking, perhaps, than any of these trough lines is the one indicated in the series of smaller streams which extend along the line c_5 of the map. These streams are too small to deserve names upon a map of this scale, but some of them are known as Five-Mile River, Whetstone Brook, Moosup River, Mt. Misery Brook, etc. The direction of the series was in fact obtained from them and applied to the other trough lines in the series. This direction, while not an observed fault direction, corresponds to the longer diagonal of two unit orographic blocks of the Pomperaug Valley placed in contact along their shorter sides (see the dotted diagonal in Fig. 1), and thus it fills an important gap in the system of dislocations outlined.

The trough lines d_1, d_2, and d_3, which trend N. ± 15° E., represent a third series. The line d_1, which corresponds in position with no very important stream, is an observed fault of the Pomperaug Valley area (extended), in which area, however, the Pomperaug River adheres closely to its direction; d_2 corresponds closely for a distance of about fifteen miles with the course of the lower Naugatuck; while to the south the lower Housatonic flows in a nearly parallel direction some distance farther to the east. Most striking of this series is the trough

line d_3, along which are arranged stretches of the West, the Quinnipiac with its tributary the Ten-Mile, the Farmington with its tributary the Pequabuck (for about fifteen miles), and a minor branch of the Farmington, which enters at its last great bend. This line, except near New Haven, is some distance east of the curving western boundary of the Newark area of the Connecticut valley.

The only important fault line observed to hold to the direction of the N. $\pm$ 20° E. faults, which is marked f on the map, follows the Quinnipiac for about fifteen miles and continued northward coincides with the course of the Connecticut for a distance of about six miles.

Following the direction N. $\pm$ 33° E. are the trough lines e_1, e_2, e_3, e_4, e_5, and e_6, the latter less marked than the others, and e_4 being an important observed fault in the Pomperaug Valley area. The line e_2 follows for a distance of fifteen miles or more, the middle course of the Housatonic; e_3 is nearly in line with the Croton and the Aspetuck rivers; while e_5 is outlined by the Pine River and the small branch of the Connecticut, which is continuous with the southwesterly flowing elbow of that river at Middletown. The line e_6 shows no striking correspondences on a map of this scale, though midway between it and e_5 the Salmon River, a branch of the Connecticut, for about seven miles follows the direction closely.

The trough lines of the N. $\pm$ 5° W. series (b_1, b_2, b_3, etc.), while not prominently marked by the courses of any great streams, save for short distances by the Housatonic, the Naugatuck, and the Connecticut, yet all show on a larger scale map in the minor stream branches many interesting correspondences. As this direction agrees more or less closely with the slope of the Cretaceous plain of erosion of southern New England, the failure of the strong streams to follow this direction is worthy of note.

Though less marked than some of the other series, the trough lines which trend N. $\pm$ 90° E. W. seem to be clearly outlined, especially h_1, which passes through the divide of the

Farmington and Quinnipiac at Plainville, and h_2, which follows the easterly course of the Connecticut for a distance below Middletown.

A trough line seems to be indicated in the Salmon River and a branch of the Willimantic (*g*). This direction is N. 48° E. and does not correspond to any observed fault direction in the Pomperaug Valley area. Neither is it the diagonal of any very simple composite block of that area, which otherwise might indicate its relationship to this system.

Conclusions.—In conclusion it may be stated that the rivers of Connecticut seem to indicate by the orientation of their channels the existence of a regular network composed of a number of intersecting series of parallel lines, which for lack of a better term have been designated *trough lines;* and, further, that with two exceptions the more important of these trough lines correspond closely in direction with the directions of fault series observed to characterize the complexly faulted area of Newark rocks in the Pomperaug Valley. Of the two exceptions to the rule, the more noteworthy one (N. ± 5° E.) fills an important gap in the system of faults determined for that area. This study is therefore in its bearing a confirmation of the conclusions arrived at by Kjerulf, Daubrée, and Brögger, who have seen in the orientation of water courses the strong directing influence of geological structure planes.

There are obviously a number of ways in which the dislocations of a region, like the one under consideration, might be made to account for the orientation of stream courses. The direction of streams by the joint or fault planes themselves may be competent to explain the network indicated, more particularly if the streams began their cutting in the soft Newark sediments, which easily sustain secondary fractures near fault planes. That some voids occur along the fault planes of the Pomperaug Valley would seem to be indicated by the fact that these planes have conducted the underground waters to the surface at so many places within the area of the Newark rocks. Tension joints should, however, be more effective than compression joints in the control of drainage

lines, if it be assumed with Daubrée that the gaping fissure planes have directed the streams in their courses. The presumptive evidence is, the writer believes, in favor of the former development of the Newark rocks over a much larger territory than that which they now occupy and probably over the entire state of Connecticut.

It is an observation of much interest that the minor twig-like branches of the streams, which in the deeply eroded mass of crystallines must have been adjusted after the capping of sandstones had been removed, show an equally strong tendency with the master streams to follow the special directions indicated by the system as a whole.[1]

The study of the fault system of the Pomperaug Basin offers, however, another rational and natural explanation of the network of streams, provided the assumption is made that the drainage is adjusted to that formed in the geographic cycle which succeeded the deformation of the area. The system of parallel faults has divided the area into vertical triangular, rhombic, or rhomboidal prisms, which stand at different relative altitudes. These prisms are found to be grouped into composite blocks of increasingly higher orders, the peculiar property of each of which is that the average altitude of its component prisms approximates (however roughly) to a fixed value—the composite blocks have an average level surface, although alternate prisms or alternate subordinate blocks for short distances project above or stand below the general level. The initial surface formed by these prisms would be marked by canal-like structure trenches (*Graben*) which follow the directions of fault planes and which have stronger directive power, as regards streams, at the junction of the trenches and at the crossings with the similar trenches of other series.

Although the numerous generally curving fault planes discovered by Davis in his extensive studies of the Newark of the Connecticut valley have here been omitted from consideration, for the reason that no close relationship to the orientation of

[1] Twenty-first Ann. Rept. U. S. Geol. Surv., Pt. III, p. 145, Fig. 52.

streams is apparent in their directions, there is no intention thereby to minimize the importance of those studies. The investigation of the smaller Newark area of Connecticut, which by contrast was almost microscopic in its detail, brought out a series of facts which for their interpretation required a totally different theory from the one to which Professor Davis was led by his studies. The two hypotheses have, however, this in common, that the primary cause of the deformation in the Newark rocks is assumed to be the compression of the crust within the area of southern New England by a force of compression, the resultant of which acted in a direction W. N. W. to E. S. E.

The present writer has been led to the conclusion that the courses of large faults within this general area, if not approximately rectilinear, are in reality zigzags, the elements of which are essentially right lines, examples of this kind being by no means rare in, and, in fact, generally characteristic of, the Pomperaug Valley. It is not impossible that many of the larger faults described by Professor Davis, if examined in greater detail, might show this peculiarity, and perhaps also fall into the system which has here and elsewhere been elaborated. The numerous broken lines which are so apparent in the boundaries of the trap hills of the Connecticut valley, as represented on the topographic atlas sheets (*e. g.*, Meriden sheet), would seem to favor this view. It is in any case important, as it would seem to the writer, to consider in two stages the dislocations brought about mainly by a lateral compression of a section of the earth's crust, inasmuch as jointing (the production of planes of separation) is in these cases a necessary prerequisite to faulting (displacement along planes of separation). The modern views of geologists concerning joint planes produced by the shear from lateral compressive stresses are now sufficiently in accord to assume that vertical block faulting takes place along ready-formed planes of jointing. In his description of the faulted area of southern Norway, Brögger[1] has been careful to make this distinction.

[1] Loc. cit.

With the explanation of the numerous diversions of rivers from their rectilinear stretches this paper is not especially concerned, although some explanation of such diversions could be found in the peculiarities of a region faulted like that of the Pomperaug Valley. The modern criteria of the physiographer deal adequately with this matter. It is the definite orientation of water courses which the new science seems to have neglected.

WILLIAM HERBERT HOBBS.

COMPOSITE GENESIS OF THE ARKANSAS VALLEY THROUGH THE OZARK HIGHLANDS

On account of its singular course through the Ozark highland region the Arkansas River presents, at the present time, unusual geological interest. Its location in this part of its course, has given rise to two very different opinions regarding the geological age of the highlands; and also regarding the question as to whether there are two distinct uplifts, as has been advocated by the Arkansas geologists, or only one, as has been urged by others who have worked in the region. Recently there have accumulated new data bearing directly upon the problem.

Topographically, the Ozark highlands comprise two imposing, nearly equal, elevated regions, separated from each other by a broad deep trough—the Arkansas River valley. The vast plain surrounding the highlands is about 400 feet above sea level on the eastern side and twice this elevation on the west side. The Arkansas River flows along on the horizon of this general grade-plain. On the south side of the river the highlands rise to heights of nearly 3000 feet above the sea; and on the north to about 1800 feet.

Diverse apparently in topographic expression, lithologic composition, geologic structure, and geological age, the district south of the Arkansas River has been known as the Ouachita Mountains, and that north of the stream the Ozark plateau. On the assumption that there are two distinct uplifts, the river of Arkansas is regarded as forming a natural dividing line between the two regions. At first glance, the simplest explanation for the position of the stream is forced upon the attention. Premising a single uplift, the accounting for the waterway's course meets with difficulties which, from superficial consideration, appear well-nigh unsurmountable. The present note attempts to sum up the evidence going to show that the facts actually sustain the second premise.

In comparing the two districts, it is their differences and not their points of resemblance which are most conspicuous. In the Ouachita region the surface relief is notably mountainous, long ridges and isolated peaks, with wide, flat-bottomed valleys intervening. In the northern district the country is far from appearing mountainous; it is, for the most part, a vast undulating plain, but sharply and deeply dissected around the borders, with the streams flowing in V-shaped valleys. In the south the rocks are more or less indurated or metamorphosed, and cut at intervals by eruptives. Nowhere in the north do the strata

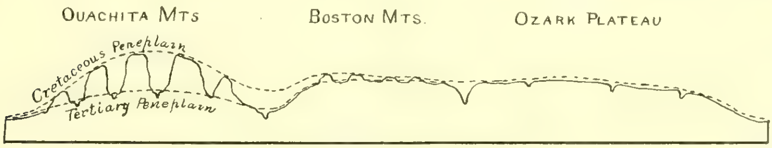


Fig. 1.— Peneplains of the Ozark region.

show alteration or evidence of the presence of eruptives. The southern district is folded to a marked degree, approaching closely the Appalachian structure; while the northern region is only gently bowed. Regarding the geological ages of the two districts, the Ouachita has been thought to have been upraised towards the close of the Carboniferous; the northern area has been commonly considered as having been an elevated region ever since pre-Cambrian times. The present uplift, however, is now believed to be of very recent origin; and the upward movement is thought to be still in progress.

The physiographical history of the region and the relations of the graded surfaces of the Ozark highlands are best indicated in diagram (Fig. 1).

Two distinct base levels are discernible in the region. They have been called the Cretaceous and the Tertiary peneplains. These titles will be retained for the present. The first of the peneplains rises out of the level savannas of the Mississippi embayment, but soon becomes deeply broken as it rises and passes into the Ouachita region. It is there believed to be

continued northward in the mountain summits, which are often flat-topped.[1] The later peneplain is thought to be represented in the intermontane flats which are about 1500 feet lower than tops of the mountains. The floor of the Arkansas valley is coincident with the Tertiary peneplain. Beyond the stream northward the Tertiary surface rises rapidly according to Hershey,[2] and soon in the region of the Boston Mountains the two peneplains practically merge. In Missouri only the Tertiary plain has been distinguished, and this is regarded as forming the general upland surface of the uplift.

It is probable that north of the Boston Mountains it will be exceedingly difficult to differentiate at any point the two peneplains. Present evidence goes to show that during the interval between the formation of the two peneplains in the south the erosion in the north was comparatively slight, and resulted in merely lowering the general surface of the plain already formed during the Cretaceous.

Some time ago it was incidentally stated that the Ozark highlands formed a single unit bowed up from the Red River to the Missouri.[3] The most obvious support for this conclusion is found in the physiographic development of the region. But the evidence is not alone from this source.

The physiographic data would indicate that in the Ozark region the uprising since Cretaceous times has been not only periodical in its character, but that it has been also differential. Lately the movement has been more marked in the north than in the south.

But there were special conditions existing that enabled the Arkansas River to hold its own against the great barrier which started to rise across its course. In a limited belt in this part of the Ozark region an enormous mass of non-resistant clay shales had been deposited in Carboniferous times. The thickness attained was much greater than that of the Carboniferous

[1] Arkansas Geol. Surv., Ann. Rept., 1890, Vol. III.

[2] American Geologist, Vol. XXVII, p. 25, 1901.

[3] Missouri Geol. Surv., Vol. VIII, p. 331, 1895.

sediments anywhere else on the American continent, being upward of 20,000 feet, according to Branner.[1] The peculiarities of this great sequence of soft shales have lately been discussed in some detail, and the real significance of the Arkansan series, as it is called, pointed out.[2]

Thus, independent of whatever geological structure the Arkansas valley may have, the enormous column of shales was of such character as to enable the great stream to scoop out a trough sufficiently vast and broad to give its topographic form

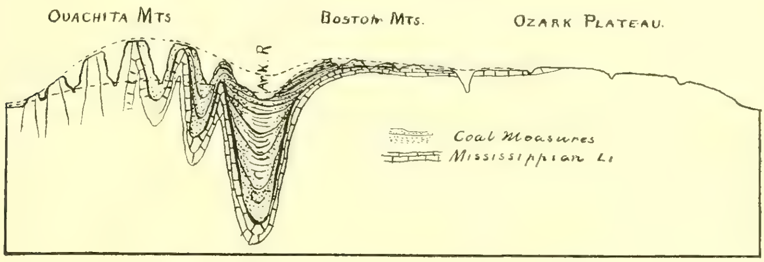


FIG. 2.— Stratigraphy of the Ozark Highlands.

the effect of a depression between two uplifts.

There is another deceptive feature connected with the valley of the Arkansas, that must be taken into consideration. Besides being a topographical trough, the valley is also a structural trough. A broad and shallow syncline stretches from the crest of the Boston Mountains to the first range of the Ouachitas. The strata closely folded in the extreme southern part of the highland district spread out rapidly towards the north until they form gentle undulations that are so characteristic of other parts of the Mississippi basin. The Ozark arch in Missouri constitutes the last great swell northward. Its southern limb passes into the broad syncline which contains the Arkansas valley. This relationship of structure is represented by a north and south cross section (Fig. 2).

The operation of different geological processes may be either

[1] Am. Jour. Sci., (4), Vol. II, p. 235, 1896.

[2] Bull. Geol. Soc. America, Vol. XII, p. 173, 1901.

all compensating, or all cumulative in their effects. Between the two extremes the sum of the antagonistic tendencies may have very variable values. The present valley of the Arkansas River as it crosses the Ozark highlands is a noteworthy illustration in which the combined effects of perfectly independent processes are curiously cumulative in character. It is on this account chiefly that the real facts concerning the development of the great uplift have been so largely obscured.

Summing up: The different geological conditions when the Arkansas River initiated its course across the Ozark region, (1) an undeformed lowland flat in which the strata had been folded to a marked degree before being beveled and the country reduced to the state of a peneplain, (2) a remarkable, yet narrow, belt, bordered on either side by resistant rocks, of soft shales of prodigious thickness which, when a new epoch of uprising was inaugurated, enabled the stream to easily keep its channel down to the general base level of the country surrounding the uplift, and (3) a broad structural trough, which, however, was only one of many synclines nearby and parallel to it—were highly cumulative in effect in imparting to the uplift the present aspect of twin elevations. By this singular combination of geological conditions the Arkansas River instead of being forced to turn aside by the great topographic dome which, out of the Cretaceous peneplain, arose athwart its path, was able to saw in two the arching strata.

Topographically, the Ozark highlands form two distinct elevated regions. Structurally as well as topographically the Arkansas valley is a trough. But structurally the Ozark highlands, as a whole, form an immense dome bowed from the Red River to the Missouri.

CHARLES R. KEYES.

A SECOND CONTRIBUTION TO THE NATURAL HISTORY OF MARL[1]

THE writer recently published a paper on the relation of algae to marl deposits.[2] Since it appeared, continued investigation has led to the discovery of additional confirmatory evidence that the close relationship there pointed out of the algae, especially Chara, to marl or lake lime deposits, exists to even a greater extent than was suspected.

Experimental work has been conducted along three lines, all of which have been fairly productive of results, and a brief account of this work may be of interest.

First, a series of mechanical analyses of typical white marl from different localities were made. The method of analysis used was a simple one, a modification of the beaker method used in soil analysis. The sample, chosen at random from a large specimen from the deposit under investigation, was dried in an air bath at 110° C. for sufficient time to remove any included moisture, and weighed. It was then mixed with distilled water in a large beaker and thoroughly stirred with a rubber-tipped glass rod, care being taken to stir it until all lumps caused by the adhesion of the finer particles to the coarser were broken up Care was also taken that no more crushing should take place than was absolutely necessary. After all lumps were disintegrated, the water, with the finer particles suspended in it, was poured off into another beaker and fresh water was added to the first and the material was again stirred. This was continued until water poured into the first beaker was nearly free from finer matter and became clear on standing a few moments. The coarse material left in the bottom of the beaker was dried, sorted into various grades by a series of sieves and each grade weighed.

[1] Printed by permission of ALFRED C. LANE, State Geologist of Michigan.

[2] JOUR. GEOL., Vol. VIII, No. 6. September–October 1900.

The finer material was also sorted by stirring, settling, and decantation, and the matter of different degrees of fineness dried and weighed. The finest matter was usually separated from the water by filtering through a dried and weighed filter, and the water concentrated by evaporation and again filtered to remove any of the calcium carbonate dissolved in the various processes, and the final residue of water was evaporated in a watch glass and weighed. An exceedingly interesting feature of this latter experiment was the finding of a water soluble calcium salt, in small proportion, it is true, but still easily weighable and not to be neglected. The results of such an analysis of a sample from the Cedar Lake marl beds in Montcalm county, Mich., gave the following results. The sample used was collected from a hole made with a spade by cutting away the turf over the marl, then taking out sufficient marl to be sure that there was no peat or other surface matter present and the material used taken from a spadeful thrown out from two or three feet below this level. From this sample about thirty grams were taken and treated as described above, and after the finer material had been separated from the coarser by washing and drying, the latter was passed through a set of standard gauge sieves, twenty, forty, sixty, eighty, and one hundred meshes to the linear inch, after which all shells and recognizable shell fragments, sand grains and vegetable débris, up to the sixty-mesh siftings, were removed and weighed separately. This gave the following grades: (1) Material too coarse to pass through the twenty-mesh sieve, (2) that held by the forty-mesh, (3) that held by the sixty-mesh, (4) that held by the eighty-mesh, (5) that held by the hundred-mesh, (6) that which passed through the hundred-mesh, (7) that which was filtered out, (8) water soluble salts, (9) shells, shell fragments, and miscellaneous matter.

The following is the result of the analysis of Cedar Lade marl made and graded as described :

Grade (1)	32.25 %
(2)	6.06
(3)	7.58
(4)	2.90
(5)	4.81
(6)	15.64
(7) (8)	30 52 [1]
(9)	0.28
	100.04

A second analysis was made from a specimen made up of twenty samples taken by boring with an auger over about one-half of the deposit at Littlefield Lake, Isabella county, most of the samples coming from a depth of at least twenty feet, six to eight meters below the surface of the deposit. This analysis gave the following results:

Grade (1)	31.52 %
(2)	14.48
(3)	12.76
(4)	2.56
(5)	6.74
(6) (7)	30.42
(8)	0.27 [2]
(9)	1.04
	99.79

A third sample, from the holdings of the Michigan Portland Cement Company at Coldwater, Mich., a fine high grade white marl, very powdery, gave the following: Weight of sample, 20.— grams.

Grade (1)	0.36 %
(2)	3.53
(3)	6.51
(4)	3.34
(5)	6.44
(6)	28.99
(7)	49.12
(8)	Not determined.
(9)	0.69
Loss and soluble matter (by difference)	1.02
	100.00

[1] In this case determined by drying down the residue and weighing.

[2] The soluble matter contains a certain undetermined amount of alkaline chlorides as well as a soluble calcium salt.

These samples represent (1) central, (2) north central, and (3) southern parts of the lower peninsula respectively, and may be taken as typical of the marl deposits of Michigan. When it is stated that, in general, it is easily possible to recognize with a simple microscope the particles which are held by the one hundred-mesh sieve, or even those which pass through it, if the finer matter has been carefully separated by washing, as characteristic Chara incrustation or Schizothrix concretions, it will be seen that these results show conclusively that a large part of the marl from these three samples is identifiable as of algal origin, and studies of the marls from other localities give similar results.

The Coldwater sample (3) was exceedingly fine in texture, and it was difficult to avoid loss in sorting and weighing, as every current of air carried away some of the particles, and some also adhered to sieves and weighing dishes in spite of all precautions. Even this sample shows nearly 50 per cent. of easily identified Chara incrustation. The fineness of the particles in a given marl bed varies much in different parts of the bed, and the degree of fineness is probably chiefly dependent upon the conditions of current and wave action under which the bed was formed, that which was deposited where the wave or current action was strong being coarser than that in stiller water or that on the lee side of exposed banks. This fact was noted at Littlefield Lake when samples of marl were collected along exposed shores above the wave line, which were 95 per cent. coarse fragments of Chara incrustation and Schizothrix nodules, while in other parts of the shore line the marl was of such fineness that it was like fine, white clay. The fragments of the Chara incrustation are generally easily recognized even when of minute size, because they preserve, usually very perfectly, the peculiar form of the stem and branches of the plant. This structure of the stem and branches is, in brief, a series of small tubes, grouped about a larger central one, and is easily seen with the unaided eye in larger fragments. Even when the tubes have been crushed, as is the case with many of the thinner ones,

it is frequently possible to recognize fragments of them with the compound microscope. Finally the incrustation is distinctly crystalline in ultimate form of the constituent particles, and when it has disintegrated the crystals and their fragments are found to constitute a large per cent. of the finer particles of the resulting marl. On the growing tips of the younger branches and the leaves of Chara, numbers of isolated crystals of calcium carbonate may be seen. Farther back on stems and branches the crystals become more numerous, then coalesce into a thin, fragile covering, and finally on the lower part of the plant the covering becomes dense and thick. It is evident therefore that the decay of the younger parts of the plants would furnish a mass of more or less free or loosely aggregated crystals of microscopic size, which would retain their crystalline form, in some degree at least, for an indefinite time and be recognizable, hence the presence of microcrystals in marl may furnish additional evidence as to the origin of the deposits.

The larger fragments of Chara incrustation as found in marl are frequently much thicker and heavier than any which occur among fragments of recent origin, *i. e.*, those obtained from any part of living, vigorously growing Chara from the beds of the plant existing in ponds from which the marl may have been obtained. While this subject needs further investigation, it is probable that such thickened incrustations have originated in several ways, the principal ones being, if the writer's notes have any bearing on the subject, as follows:

1. On short, stunted plants that grow for a long time on unfavorable soil, such as sand or pure marl. Such plants have relatively very short internodes and generally thick incrustations, much thicker than those on plants growing normally.

2. From the growth of the lime-secreting, blue-green algae, such as Schizothrix, Rivularia, etc., either upon living chara or upon the fragments of broken incrustation, as a nucleus. Such a growth might produce considerable thickening of the Chara incrustation.

3. From the inclusion of the fragments within the nodules

formed by the growth of the incrusting blue-green algae, in shallow water, and the subsequent destruction of the nodules by wave or other disintegrating action. In this case a thickened fragment may be left either free or attached to other material. Several fragments may be cemented together, and such aggregations have been observed.

4. By the deposition of calcium carbonate on fragments of incrustation, the source of the salt deposited being soluble calcium-organic compounds left free in the water by the decay of dead Chara, the precipitation being caused by the reducing action of chemical compounds derived from the decay of organic matter or the growth of bacteria. It may be conceived also that the calcium carbonate thus deposited might also act as a cementing material to fasten the finer particles of marl to the incrustation as a nucleus.

5. By the deposition in more or less coarsely crystalline form of calcium carbonate which is dissolved by water percolating through the marl. This is probably considerable in amount and takes place in a manner analogous to, if not identical with, the formation of concretions in clays and shales. It is probable that in this way the crystals may be formed, which rather rarely are found filling the cavities in the Chara incrustations, left by the large axial cells of the plant. The fact that in the great majority of cases these cell cavities are entirely empty or are simply mechanically filled with fine particles of marl, is a most serious objection to considering that this form of chemical precipitation is an important one in the history of marl, but that it is occasionally operative is extremely probable.

6. It is possible that the thick incrustations may have been formed at some earlier period in the history of the lakes when conditions for the development of the plant forms and their activities were greater. This is not probable however, for the thick incrustations are often found from the surface of the marl beds throughout the entire deposits.

In addition to the marl analyses given above a check analysis was made of a specimen of material made up from the washings

and fragments of a mass of Chara plants collected from Cedar Lake, and allowed to die slowly and to break up in water kept cold and fresh by conducting a small stream from the hydrant through it. The plants gradually died, broke up, and settled to the bottom of the containing vessel and seemed to undergo farther disintegration there from the growth of fungi, eventually forming a relatively finely divided deposit which was of rather dark color, when wet. A quantity of this was dried at 100°C., some of the longer and larger fragments of stems were removed, and the residue was weighed and subjected to the same treatment as the marl samples. The analysis gave the following:

Grade (1)	1.12%
(2)	24.43
(3)	14.63
(4)	8.26
(5)	7.81
(6) (7)	33.83
(8)	0.39
(9)	0.12
Soluble organic matter and loss	9.41
	100.00

It will be seen that nearly as much fine matter was present in this material as in the finest of the marls analyzed, and that the finer grades of sifted material are quite as well represented as in the finer marl. The material is somewhat more bulky for a given weight and is perhaps slightly darker in color, but not much more so than many samples of marl.

Grade for grade it is identical in appearance and structure to the marl samples, and the only possible difference that can be detected is the slightly green tint and the organic matter present in the plant residue. It is also noticeable that the larger pieces do not show as thick an incrustation as do the larger pieces from the marl samples and, of course, Schizothrix and other coarse matter is not present.

It will be seen by inspecting the analyses, that shells and recognizable shell fragments are but a very insignificant part of

the total quantity of the marl. It is surprisingly small when all things are taken into account. While it is probably true that not all the minute shell fragments have been separated in any of these analyses, it is also true that the weight of such overlooked particles is more than counterbalanced by marl fragments which are included within the cavities of the whole shells, and adhere to both broken and whole shells in crevices and sculpturings in such a way as to refuse to become separated in the processes of washing out the marl. The whole shells are mainly small, fragile forms, many of them immature, and it is evident that they would be broken by any action that would crush the Chara incrustation.

A second line of investigation took into consideration the milky appearance of the waters of some marl lakes. This has been considered by some investigators as possibly due to the presence of calcium carbonate precipitated from the water either by the liberation of dissolved carbon dioxid from the water and hence from the calcium bicarbonate or by change of temperature of the water after it has reached the lakes.

The writer has not found among the marl lakes of the southern peninsula of Michigan that those with turbid water were common, even where marl banks were apparently forming with considerable rapidity.

"Merl" or Marl Lake in Montcalm county, situated on the same stream as Cedar Lake and a mile or more below it, is, however, one of the lakes in which the water is usually of almost milky whiteness, and has sufficient suspended matter in it to render it nearly opaque for depths of a meter or a little more. The conditions in this lake are widely different from those at Cedar Lake and other marl lakes in the vicinity and are suggestive of the cause of the turbidity. At Cedar Lake there is a border of grassy or sedgy marsh extending around the lake on three sides and generally underlaid by marl, and the lake bottom slopes sharply and abruptly from the edge of the marsh to a depth of at least ten meters. In other words the lake is simply a deep hole, with steep sides, and perhaps represents the

deepest part of the more extensive lake which formerly occupied the area included by the marsh and marl beds. This marsh covering is general on the marl beds of the region and the lake may be said to be a typical marl lake for the locality in which it lies, for there are several others near by which are practically identical in essential points of structure.

At Marl Lake, however, the filling of the lake has not reached the same stage. There is practically no open marsh, but the lake is shallow for seventy-five or a hundred meters from the shore, then abruptly deepens to an undetermined depth over a relatively small area. The bottom over the shallow area is of pure white marl, and the water is apparently not more than sixty or seventy centimeters deep at the margin of the central hole, while near the shore it is scarcely one-third as deep. In brief, here is a lake in which there is a broad platform of marl surrounding a deep hole, which again is all that remains of the deep water of a lake which is filling with marl. Boring shows that the bed of the lake is nearly as far below the surface under the marl platform, as where the marl has not yet been deposited.

Upon the shoreward edges of the platform and in small areas farther out upon it, the turf-forming plants are beginning to establish themselves, but as yet they have not made any marked impression, seeming to have a hard struggle to get a foothold. The conditions are then a broad area of shallow water overlying a wide platform of marl, which, if a strong wind should reach it, would be stirred to its depths, and with it the lighter parts of the marl upon which it rests. The marl thus stirred up, in turn, is carried to all parts of the lake by surface and other currents and makes the water turbid. These facts led to an investigation as to the rapidity with which marl, once stirred up, would settle out of perfectly still water, and some interesting results were obtained. The experiments were made as follows: (1) A glass tube 1.58 meters long and 2.5 centimeters wide was filled with distilled water, into which a quantity of finely divided marl was turned and the tube was shaken to insure a thorough mixing of water and marl. The tube was then

clamped into a vertical position and left perfectly still until the marl had settled out, notes being made, daily at first, of the rate of settling. In the beginning, the heavier particles settled rapidly, forming, as does clay in settling from water with which it is mixed, stratification planes, which, however, after a few days disappeared, and only the lighter parts of the marl remained in suspension. These were distinctly visible for five weeks, on looking through the tube towards a window, and at the end of six weeks, a black object lowered into the tube in a well-lighted room, was not visible beyond ninety centimeters from the surface of the water. (2) A glass cylinder with a foot, 38^{cm} high and 7^{cm} wide, having a capacity of a little more than a liter was nearly filled with distilled water and the residue from the washings of a sample used in analysis was thoroughly mixed with it, and set aside, notes being made as before. This material subsided rather more slowly than the other, and at the end of ten weeks, under daylight illumination, the bottom of the vessel was barely visible when one looked down through the water from above.

The results obtained by Barus[1] in his work on the subsidence of solid matter into suspension, in liquids, show that settling is much more rapid in water containing dissolved salts, even small proportion, than in distilled water, and the foregoing experiments were checked as follows: (1) A cylinder about the size of the one used in the second experiment was filled with water in which a small amount of calcium chlorid had been dissolved, and ammonium carbonate was added until a precipitate was formed. This was stirred thoroughly and left to settle. In three days the precipitate had fully subsided and the liquid was clear. (2) Two cylinders of equal size were filled, one with distilled water, the other with water from a river fed, in part, by marl lakes. Equal quantities of fine marl were shaken up with the water and the rate of settling was compared. The marl was not as fine as that used in the other studies and settled more rapidly. The river water was clear in fifteen days, while the

[1] CARL BARUS: "Subsidence of Fine Solid Particles in Liquids." Bull. of the U. S. Geol. Surv., No. 36.

distilled water was not clear when the experiment terminated, but was nearly so, showing that the subsidence was not quite so rapid in distilled water as in natural lake or river water.

These results indicate that, if for any cause the marl in a marl lake is stirred up effectually, as it may be in those where the beds are exposed to wave action, the water will remain turbid for some time; even in summer time the chances are that there will be sufficiently frequent high winds to keep the water always turbid. It may be stated that in some of the lakes which have been studied by the writer, the marl beds have filled the entire lake to within a fraction of a meter of the surface of the water, with some parts only a few centimeters deep. Until such shallows are occupied by vegetation the water is likely to be turbid from the mechanical action of waves upon the deposits. At Littlefield Lake, described elsewhere,[1] the water is only slightly turbid, although there are extensive shallows and exposed banks, but there the body of water is extensive and of considerable depth, while the greater part of the exposed marl is granular and the particles too coarse to be held long in suspension, and the finer deposits too small and too well protected to be reached by effective waves, so that the amount of suspended marl is not great enough to produce marked turbidity in the entire body of water.

It may be worthy of note that the residue of suspended matter, filtered out from the sample of Chara fragments (analysis (4) above) was sufficiently fine to give a marked turbidity to distilled water for several days, and at the time of filtering had not subsided, demonstrating the fact that very finely divided particles may originate from the simple breaking up of the Chara plants by ordinary decomposition of the vegetable matter.

It is difficult to account for the fact that the deeper parts of marl lakes are generally free from any thick deposits of a calcareous nature. Lack of records of sufficient exploration makes any statement purely tentative, but about seven to nine meters[2]

[1] C. A. Davis: "A Remarkable Marl Lake," Jour. Geol., Vol. VIII, No. 6.

[2] Wesenberg-Lund: Lake-Lime, Pea Ore, Lake Gytje. Saertryk af Meddelelser fra Dansk Geologisk Forening, No. 7, p. 156.

seems to be the limit of depth of recorded occurrence of Chara plants. The remains of the plants, then, would only accumulate, in place, above that depth, and the material reaching greater depths would be that held in suspension in the water, and hence be relatively very small in quantity and accumulate slowly. A possible additional cause of slow accumulation is that in the greater depths, *i. e.*, over ten meters, the greater abundance of dissolved carbon dioxid held in solution by pressure dissolves the finer particles of marl which reach these depths.

From these investigations it seems (1) that marl, even of the very white pulverulent type, is really made up of a mixture of coarser and finer matter covered up and concealed by the finer particles, which act as the binding material. (2) That the coarser material is present in the proportion of from 50 to 95 per cent. (3) That this coarser material is easily recognizable with the unaided eye and hand lens, as the incrustation produced on the algae, Schizothrix and Chara, principally the latter, to particles less than one one-hundredth of an inch in diameter. (4) That the finer matter is largely recognizable under the compound microscope as crystalline in structure, and is derived from the algal incrustation by the breaking up, through decay of the plants, of the thinner and more fragile parts, or by disintegration of the younger parts not fully covered. (5) That some of this finer matter is capable of remaining suspended in water a sufficiently long time, after being shaken up with it, to make it unnecessary to advance any other hypothesis to explain the turbidity of the waters of some marl lakes, than that it is caused by mechanical stirring up the marl by wave or other agency. (6) That shells and shell remains are not important factors in the production of the marl beds which are of largest extent. (7) That there is in marl a small amount of a water soluble calcium salt, readily soluble in distilled water, after complete evaporation.

[2] A. J. PIETERS: Plants of Lake St. Clair, Bull. Mich. Fish Commission, No. 2, p. 6.

Studies were undertaken to determine the method of concentration and precipitation of the calcium carbonate by Chara.

As has already been indicated elsewhere, the calcium carbonate is present on the outside of the plant as an incrustation, and this is made up of crystals, which are rather remote and scattered on the growing parts of the plants, and form a complete covering on the older parts, which is uniformly thicker on the basal joints of the stems than it is on the upper ones. Considering the hypothesis that the deposition of the salt was the result of purely external chemical action as not fully capable of satisfying all the existing conditions, the formation of the incrustation was taken up as a biological problem, and an investigation was made upon the cell contents of Chara, first, microscopically by the study of thin sections. Various parts of the plant were sectioned while still living, and the attempt was made to find out if the calcium carbonate was present as a part of the cell contents in recognizable crystalline form. Various parts of the plant were examined, but no crystals undoubtedly in place among the contents of the cells were observed, although numbers were to be seen on outside walls of all cells.

Next an attempt was made to determine the presence of the calcium in soluble form in the cell contents, by the use of dilute neutral solution of ammonium oxalate. An immediate response to the test was received by the formation of large numbers of minute, characteristic, octahedral crystals of calcium oxalate on the surface and imbedded in the contracted protoplasmic contents of the cell. The number of these crystals was so large, and they were so evenly distributed through the cell contents, that it was evident that a large amount of some soluble calcium salt was diffused through the cell sap of the plant. The next step was to isolate this compound and to determine its composition. A considerable quantity of the growing tips of Chara were rubbed up in a mortar and the pulp was thoroughly extracted with distilled water. This water extract was filtered and tested to determine the presence of calcium and an abundant precipitate obtained by using ammonium oxalate,

which, on being separated and tested, proved to be calcium oxalate. It was evident that the calcium salt in the plant was stable and readily soluble in water. This latter fact was farther demonstrated by evaporating some of the extract to dryness and again taking it up with water. Almost the entire amount of the calcium salt was redissolved, only a small portion of it becoming insoluble and precipitating as the carbonate. This ready solubility demonstrated the fact that the salt was not derived from the incrustation on portions of the plant used, and the same fact excluded from the list of possible compounds, salts of some of the mere common organic acids found in plant juices, which are insoluble.

Qualitative chemical tests were, however, made to determine, if possible, whether any of these acids were present with negative results, and it was demonstrated by this means that there was but a single salt present and not a mixture. Search was then made to determine the acid present, and a result obtained which was so unexpected that it was seriously questioned and the work was gone over again. The second result confirmed the the first and the work of ascertaining the correctness of these two results was turned over to Mr. F. E. West, Instructor in Chemistry in Alma College, who had had special training and much practice in organic analysis. His work was done entirely independently, with material gathered at a different season, and by another method of analysis, but his results were identical with my own, and show that calcium exists in the water extract of Chara as calcium succinate. The fact that the succinate is one of the few water soluble calcium salts and that there is a soluble salt of the metal in the cell sap of the plant makes it probable that this is the compound of the metal which the plant accumulates in its cells.

It is not possible from actual investigation to explain the method by which the calcium salt is abstracted from the water, where it exists as the acid- or bi-carbonate or the sulphate[1] in

[1] It has been shown that Chara decomposes several calcium salts, the sulphate among others.

small per cent., and is concentrated in the cells of the plant as calcium succinate and later deposited upon the outside of the same cells as the normal or monocarbonate in crystalline form in considerable quantities.

Some culture experiments which were undertaken by the writer to determine under what conditions of soil, light, and temperature Chara thrives best, incidentally demonstrated that the plant actually gets its lime from the water and not from the soil. One of the soils which was used as a substratum in which to grow plants was pure quartz sea-sand which had been washed with acid to remove any traces of calcium salt which might be present. The plants grew in this medium readily, and on the newer parts developed nearly, if not quite, as many calcium carbonate crystals as plants growing in pure marl. It should be apparent, however, to even the casual observer that the plants cannot take all the lime they precipitate from the soil, or even a considerable part of it, for if they did the marl beds, being made up principally of Chara remains, would never have accumulated, for the material would have been used over and over again and could not increase much in amount, if it increased at all. In the present state of our knowledge of the life processes of aquatic plants, it seems hardly possible to state the probable method of the formation of the calcium succinate, or even the probable use of it to the plant, and no attempt will be made by the writer in the present paper to do so. It does seem probable, however, that this compound accumulates in the cells, until it reaches sufficient density to begin to diffuse through the cell walls by osmosis. Outside the cells, or in its passage through the walls, it is decomposed directly into the carbonate, possibly by oxidation of the succinic acid by free oxygen given off by the plants, possibly by some substance in the cell walls, or, more probably, by the decomposition of the acid by some of the organic compounds in the water, such as the organic ferments, due to bacterial growth in the organic débris at the bottom of the mass of growing Chara. The water extract of Chara rapidly changes on standing, undergoing putrefactive

decomposition, becomes exceedingly offensive in odors developed, and calcium carbonate crystallizes out on the bottom and sides of the containing vessel, while the succinic acid disappears, gas, possibly carbon dioxid, being given off more or less abundantly. Whether these changes takes place on the outside of the living plants, in the cell walls, or in the water surrounding the plants has not yet been determined.

Sufficient evidence is here presented, however, if the writer's conclusions are correct, to show that the plants under discussion are active agents in the concentration of calcium salts in the fresh water lakes of Michigan, and that they alone have produced a very large part of the marl which has accumulated in these lakes. It seems probable also that the principles developed by these studies are of very wide application in working out problems presented by formations developed under similar conditions elsewhere.

Charles A. Davis.

Alma College,
July 1, 1901.

PERKNITE (LIME-MAGNESIA ROCKS)[1]

THERE are sometimes associated with diorites, gabbros and peridotites, dark rocks composed largely, or entirely, of monoclinic amphibole or pyroxene, or both. These rocks differ mineralogically from diorites and gabbros, in containing little or no feldspar, and from peridotites in containing rhombic pyroxine or olivine in relatively small amount, if present at all. Chemically these rocks contain less alumina than diorites and gabbros, and less magnesia than peridotites. They are low in alumina and in the alkalis, moderately rich in lime, magnesia, and the iron oxides.

The chief constituents of perknite are monoclinic amphibole and monoclinic pyroxene; the secondary constituents rhombic pyroxene, olivine and feldspar; the accessories biotite, iron ore, etc., but only one of the primary constituents may be present with none of the secondary constituents or accessories. The existence of this group of rocks has long been recognized, but from their occurrence usually in small masses, and from the fact that many of them are of simple composition so that the self-explanatory names pyroxenite and amphibolite or hornblendite have answered, they have never been grouped together under one name.

In the State of New York[2] and in California[3] there are rocks containing both monoclinic pyroxene and amphibole as principal constituents, and doubtless this is likewise the case in many other parts of the world. Moreover, in California such rocks form areas of geological importance. There is, therefore, some reason in grouping all of these lime-magnesia rocks under a common name. It is proposed to call the group *perknite* from

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] G. H. WILLIAMS: Am. Jour. Sci., Vol. XXXI, 1886, p. 40.

[3] TURNER: Am. Jour. Sci., Vol. V, 1898, p. 423. Turner and Ransome. Sonora folio.

the Greek word περκνος, meaning dark. It will include granolites of the following specific names:

Pyroxenite.

Hornblendite (Williams).

Websterite (Diallage and ortho-rhombic pyroxene) (Williams).

Diallagite.

Hornblende-hypersthene rock (Merrill).

Amphibole-pyroxene rock (Turner).

The group may be graphically represented by the method employed by Hobbs[1] and his representation of a composite pyroxenite will approximate to that of a typical perknite. The following table of analyses will give the reader a notion of the composition of the rocks which may be properly included in this group.

1. *Hornblendite.*—Geo. Steiger, analyst. This partial analysis is here published for the first time. The rock is from a dike cutting through the basement complex and overlying Cambrian rocks, 2 km north of Silver Peak village, in Esmeralda county, Nev. It is composed chiefly of green hornblende with some feldspar. The rock grades into a basic diorite.

2. *Amphibole-pyroxene rock.*—W. F. Hillebrand, analyst. Not before published. Rocks of this type are very abundant in Mariposa county, Cal. Mr. F. M. Anderson, of the University of California, has likewise collected them in northern California. This rock in its typical development is composed of original pyroxene and amphibole in grains of nearly equal size, with a little quartz and pyrrhotite. Scattered through the rock are phenocrysts about one centimeter in diameter, of brown amphibole, which contain in a poikilitic manner, as inclusions, the constituents of the groundmass.

3. *Perknite* (author's name, *peridotite*).—Belchertown. Bull. U. S. Geol. Survey, No. 168, p. 30. L. G. Eakins, analyst. The rock is composed of hornblende, pyroxene, biotite, olivine and magnetite.

[1] Jour. Geol., Vol. VIII, 1900, p. 14.

ANALYSES OF PERKNITES; LIME-MAGNESIA ROCKS.

Name	I Hornblendite	II Amphibole-pyroxene rock	III Perknite	IV Pyroxonite	V Websterite	VI Websterite	VII Composite pyroxonite
SiO_2	46.28	48.04	48.63	50.80	53.25	53.21	52.58
Al_2O_3	.....	7.82	5.32	3.40	2.80	1.94	3.69
Fe_2O_3	.....	2.01	2.91	1.39	.69	1.44	1.90
FeO	.....	9.32[1]	3.90	8.11	5.93	7.92	6.50
MgO........	19.54	13.33	21.79	22.77	19.91	20.78	20.86
CaO	9.91	13.01	13.04	12.31	16.22	13.12	13.23
Na_2O.......	2.21	.69	.34	trace	.19	.11	.22
K_2O........	1.89	.48	.23		trace	.07	.10
$H_2O-110°C$	.....	.17	2.81	.52	.05	.14	.57
$H_2O+110°C$	.....	2.90			.24	.87	
TiO_2	.....	1.16	.47	none	.....	.26	.11
ZrO_2	.....	.....	.....	.....	.....	trace	....
CO_2........	.....	none	trace	.....	.....	.10	....
P_2O_5	.....	trace	.21	trace	.....	trace	....
SO_3	.....	.23[2]	.....	trace	.....	.....	....
S	.....	.90	.....	Cl. .24	.....	FeS_2 .03	....
V_2O_3.......	.....	.....	.....	.....	.....	.03	....
Cr_2O_3	.....	.90	.36	.32	.54	.20	....
NiO	.....	.....	.....	.....	.07	NiO + CoO .03	....
MnO........	.....	none	.12	.17	.09	.22	.11
BaO	.....	none	trace	.....	.....	none	other constituents
SrO	.....	.....	.....	.....	.....	none	.50
Li_2O	.....	.....	.....	.....	.....	trace	....
Total.....	.....	100.06	100.13	100.03	99.98	100.47	100.49
Less O....	.....	.45					
		99.61					

4. *Pyroxenite.*—Johnnycake road, Baltimore. Bull. U. S. Geol. Survey, No. 168, p. 42. Composed entirely of hypersthene and diallage.

5. *Websterite.*—From Mt. Diablo. W. H. Melville, analyst. Bull U. S. Geol. Survey, No. 168, p. 213, and Bull. Geol. Soc. Am., Vol. II, p. 406; analysis No. 242. The rock is composed of orthorhombic pyroxene and diallage.

[1] Owing to analytical reasons this determination of ferrous iron is unsatisfactory.—W. F. Hillebrand.

[2] This determination somewhat doubtful.—W. F. H.

6. *Websterite.*—Oakwood, Cecil county, Md. Composed of hypersthene and diallage. W. F. Hillebrand, analyst. Bull. U. S. Geol. Survey, No. 168, p. 43.

7. *Composite pyroxenite.*—Hobbs, JOUR. GEOL., Vol. VIII, p. 30. This analysis is a composite from three analyses of pyroxenites, and one analysis of a hornblende-hypersthene rock from Gallatin county, Mont.

Professor J. S. Diller, in his bulletin on "The Educational Series of Rock Specimens,"[1] introduces three specimens which would fall into the perknite group.

No. 110, a pyroxenite, is described by Professor George H. Williams.

No. 111, feldspathic peridotite, is described by Professor George H. Williams.

No. 113, Cortlandite (hornblende-peridotite), is described by Williams and Iddings. The rock is composed of brown hornblende, olivine, pyroxene, biotite, feldspar, and magnetite.

Some rocks that have been termed wehrlite will fall also into this group.

EFFUSIVE AND DIKE ROCKS

Corresponding to the plutonic group of perknite there undoubtedly occur effusive and dike rocks. Professor Rosenbusch regards hornblende-picrites as effusive, and some of these have the chemical and mineral composition of perknite. This will also be true of augitites, since in these augite or monoclinic pyroxene is the chief constituent.

Professor J. P. Iddings has been kind enough to criticise the above paper and calls my attention to the fact that my definition of perknite would bring into the group the kimberlite of Kentucky with 9.46 per cent. of lime, and the kimberlite of South Africa with 9.60 per cent. of lime, as wellas the amphibole-peridotite of Schriesheim with 7.22 per cent. of lime. He also calls attention to the fact that with hypersthene-enstatite rocks there

[1] Bull. U. S. Geol. Surv., No. 168.

may be very little lime present and yet they would not be peridotite. This brings us to the re-definition of peridotite, and I should define a peridotite chemically as a magnesia rock with usually less than 6 per cent. of lime. This would put a rock composed entirely of hypersthene or enstatite with the peridotites, where they certainly belong chemically.

H. W. Turner.

San Francisco, Cal.,
June 20, 1901.

THE BORDER-LINE BETWEEN PALEOZOIC AND MESOZOIC IN WESTERN AMERICA

THERE have been in recent years in America many controversies as to the Silurian-Devonian and the Devonian-Carboniferous boundaries; but American geologists have always felt secure as to the line of demarcation between the Paleozoic and the Mesozoic. This has always been thought to be marked by a grand chasm, a hiatus in stratigraphy and a break in life, accompanying a great change in physical geography, all of which is true of the region east of the Rocky Mountains.

But later discoveries in the Great Basin region have shown that the gap is at least partly filled out by marine sediments, and that the hiatus is not universal in America. The most important of these discoveries was the finding of marine Permian in northern Texas, with forms suggestive of the Mesozoic types of life, and the finding in southeastern Idaho of marine Lower Trias, with a fauna reminiscent of the Paleozoic.

Recently there has been evident among geologists a tendency to revert to first conditions in determining the boundaries of geologic systems. They have been inclined to use unconformities as the dividing lines between geologic groups, and to look upon geologic systems as realities, and not mere names for the convenience of stratigraphers. This must mean that they regard the geologic events that delimited the systems as of world-wide effectiveness, or even of cosmic origin. But almost every trangression of the sea has been found to be balanced by a retreat elsewhere, every uplift to have its correlative subsidence. And in still other parts of the earth there may have been neither uplift nor subsidence. Even the Appalachian revolution did not effect the western Carboniferous Sea, and this is generally admitted to have been one of the greatest events in the dynamic history of North America.

In defining the upper Paleozoic and the lower Mesozoic no

account was taken of conditions of formation, and this has led to endless difficulties in correlation. The Upper Carboniferous was based entirely on lacustrine deposits, and the identification of its marine equivalent is still making trouble for geologists. The Permian was based on a basin deposit, partly lacustrine and partly of brackish water origin, and the recognition of its purely marine types has caused much controversy in Europe and America. The Trias was based at first entirely on the deposits of the Germanic inland sea, and only recently has any uniformity been attained in its correlation and nomenclature.

The greater divisions are now all named, and there is no room for new systems, all geologic time, and possibly something over, being taken up by those already defined. But because the first naming of geologic divisions was based on unconformities, which represented erosion intervals and consequent gaps in the record, further exploration must necessarily bring to light somewhere in the world passage beds between the artificial systems. What rules then shall be followed in the correlation of these passage-beds, or new formations? If the new formations are shown to be the homotaxial equivalents of parts of systems already defined, there can be no question, for faunal or lithologic differences cannot be taken in account in different provinces or regions.

If the new formation, however, lies between two systems, one of which is sharply defined and the other described only vaguely, as including the beds below or above the one with definite boundaries, then the passage-beds must naturally be assigned to the system with a flexible margin.

If both the bordering systems should be definitely bounded, or if neither should be, then one or the other must be stretched to take in the passage-beds, and the assignment will be based on paleontologic relationship to one or the other. But if this relationship should be no closer to one than the other, then priority of assignment would have to decide on the nomenclature of the doubtful beds.

The geologists of India have for many years recognized that

in the Himalayas and the Salt Range there was a continuity of life and sedimentation from the Paleozoic into the Mesozoic, and there the line of demarcation has been arbitrary. The stages or zones used in drawing this paleontologic line in India have become types, and are used in interregional correlation wherever similar beds are known. A section is given below of the uppermost Permian and the Lower Trias of India, for convenience of comparison with the American section.

SECTION OF THE PERMIAN AND LOWER TRIAS OF INDIA AFTER WAAGEN, DIENER, AND NOETLING

Trias	Middle	Upper Ceratite limestone.	
	Lower	Ceratite sandstone	Flemingites beds.
			Stachella beds.
		Otoceras beds	Ceratite marls.
			Lower Ceratite limestone.
Permian	Upper	Upper Productus limestone, with *Cyclolobus oldhami*, and *Xenaspis carbonaria*.	
		Middle Productus limestone, with *Xenaspis carbonaria*.	
	Lower	Lower Productus limestone, with *Fusulina kattaensis*.	
		Glacial beds.	

Waagen drew the line between Paleozoic and Mesozoic at the base of the Ceratite formation because of a supposed unconformity, and because the Permian types of brachiopods such as *Productus*, *Chonetes*, and the Orthidae have not been found above this line. But the unconformity has since been shown not to exist, and several of the Permian ammonite genera range up into the Ceratite formation, such as *Otoceras*, *Medlicottia* and *Xenaspis*.

The upper Productus limestone is acknowledged to be younger than any known European marine Permian, and the *Otoceras* beds are universally considered to be older than any Trias yet known from Europe; therefore the continuity of sedimentation and life makes it exceedingly difficult to draw a line that will satisfy everybody. And, indeed, if either the Trias or the Permian had been named first in India, there would have been no division of this series.

The Wichita Permian of Texas, while carrying forms such as *Medlicottia*, *Waagenoceras*, and *Popanoceras*, harbingers of the varied Triassic ammonites of later times, contains in its other members so many Paleozoic types that no one would think of

classing it in the Mesozoic. There can be no controversy as to its age, which is approximately equivalent to that of the lower Productus limestone of India. It lies conformably on the Coal-measures, and contains many species that have ranged up from the latter.

But above the Wichita Permian lies the great series of the Red Beds. These have been assigned sometimes to the Permian and sometimes to the Trias, and they, doubtless, belong to both. Marine fossils have been found in these Red Beds only in three places. The Geological Survey of Texas [1] found in the Double Mountain formation at the falls of Salt Croton Creek, Kent county, Texas, *Medlicottia*, *Waagenoceras*, and *Pleurophorus*, all akin to forms from the Wichita beds. The writer has examined these forms and recognizes them to be still typically Permian in character, although they are very near the top of the formation. Above these beds lies the fresh water "Dockum" series referred by Cope to the Trias.

C. N. Gould [2] has recently found marine and brackish-water Permian fossils in the Red Beds of Oklahoma, in the Cimmaron series; the forms still being of Paleozoic type, such as *Conocardium*, *Aviculopecten*, *Schizodus*, *Pleurophorus*, and *Bakevellia*. The stratigraphic position of these is equivalent to the Double Mountain beds of Texas, and they belong unequivocally to the Paleozoic.

In the Red Beds of Utah, at Ft. Douglas near Salt Lake City, F. Frech [3] has found *Pleurophorus imbricatus* Waagen, *Allorisma* conf. *elegans* King, *Emondia aspinwallensis* Meek, *Schizodus schlotheimi* King, and *Dalmanella* sp. indet., a fauna that would pass for Paleozoic anywhere, and belongs in the same horizon as the Double Mountain beds of Texas and the Cimmaron series of Oklahoma and Kansas. They are the homotaxial equivalents of the Upper Permian.

[1] Geological Survey of Texas, Second Annual Report, 1890. Report on the Geology of Northwestern Texas, by W. F. CUMMINS, p. 408.

[2] JOUR. GEOL., Vol. IX, 1901. No. 4, p. 337.

[3] Lethaea Geognostica, Vol. II, Lieferung 3. 1900, p. 515.

From the close of the Coal-measures the land encroached on the basin-sea by a progressive westward uplift, and the brackish water and basin deposits take a successively higher place in the geologic column towards the west. Thus somewhere in the eastern part of the Great Basin region marine intercalations of Lower Trias may be expected to be found in the Red Beds. Indeed, this formation in southeastern Idaho lies above and conformably upon the marine limestones with a Lower Triassic fauna. It is, then, in the upper part of this Red Beds formation, in the fresh and brackish-water deposits and its rare marine facies, that we are to seek for the transition from Paleozoic to Mesozoic.

C. A. White[1] has described from the Aspen Mountains of Idaho a marine fauna older than any Trias known up to that time in America, and younger than any known Permian. The Meekoceras beds in which this fauna was found he assigned to the Lower Trias. According to A. C. Peale[2] this formation lies conformably upon the Carboniferous, and below the Red Beds. The *Meekoceras* fauna was found near the base of the series, which here has a thickness approximating three thousand feet. The Carboniferous limestone below contained *Productus multistriatus* Meek, which has been found by the writer in the uppermost Paleozoic beds of California, and has been cited as a characteristic fossil of the Permian of northern Europe.

Since that time Professor Alpheus Hyatt and the writer have visited the Meekoceras beds, and their joint collections yielded; *Meekoceras gracilitatis* White, *M.* (*Gyronites*) *aplanatum* White, *M.* (*Koninckites*) *mushbachanum* White, *Aspidites*, *Flemingites*, *Pseudosageceras*, *Ussuria*, *Ophiceras*, *Clypites*, *Danubites*, *Nannites*, and a number of new genera.

The writer[3] has previously described the Ceratite limestone of the Lower Trias of Inyo county, California. During the past

[1] Twelfth Ann. Rep. U. S. Geol. and Geog. Surv. Terr., Part I (1880). Triassic Fossils from Southeastern Idaho.

[2] Bull. U. S. Geol. and Geog. Surv. Terr., Vol. V., No. 1 (1879). Jura-Trias Section of Southeastern Idaho and Western Wyoming, p. 119.

[3] Jour. Geol., Vol. VI, No. 8, 1898. Geographic Relations of the Trias of California.

winter he has visited this locality and added a great many species and genera to the collection from that formation. Those now known from there are: *Meekoceras gracilitatis* White, *M.* (*Gyronites*) *aplanatum* White, *M.* (*Koninckites*) *mushbachanum* White, *M.* conf. *radiosum* Waagen, *M.* conf. *falcatum* Waagen, *M.* aff. *boreale* Diener, *Aspidites*, *Prionolobus*, *Danubites*, *Proptychites*, *Xenaspis*, *Lecanites*, *Nannites*, *Ussuria*, *Pseudosageceras*, and *Clypites*, besides a number of new genera. Several of the species, both new and described, are identical with forms from the *Meekoceras* beds of southeastern Idaho, with no greater difference in the fauna than might be expected in localities separated by six hundred miles.

Below the *Meekoceras* beds of Inyo county lie several hundred feet of barren shales, and below these is siliceous limestone containing *Fusulina*. Above the *Meekoceras* beds are eight hundred feet of calcareous shales with impressions of ammonites, and then a few feet of black limestone with *Acrochordiceras*, *Hungarites*, *Tirolites*, *Ceratites*, and *Xenodiscus*, and *Parapopanoceras*, probably belonging to the base of the Middle Trias. The entire series appears to be conformable, from the Upper Carboniferous to the Middle Trias.

The fauna of the *Meekoceras* beds of Idaho and California is most intimately related to that of the Ceratite formation of India, and of the homotaxial *Proptychites* beds of Ussuri in eastern Siberia. *Meekoceras*, *Gyronites*, *Koninckites*, *Danubites*, *Proptychites*, and *Ophiceras* are known both in the Ceratite formation of India, and in the Ussuri beds of Siberia; *Pseudosageceras* and *Ussuria* are known elsewhere only in the Ussuri formation; and the species of all these regions are nearly related, in part apparently identical.

It is, therefore, plain that the correlation of the Ceratite formation of India has a direct bearing on the determination of the age of the Meekoceras beds of America. Albert Oppel, who in 1865 described fossils from the Ceratite formation of India, referred them at first to the Jura, and then afterwards to the Trias, as typical Jurassic beds were found considerably above

them. But before this, in 1863, de Koninck, who also described a number of ammonites from the Ceratite formation, referred them very doubtfully to the Paleozoic, because they were supposed to have come from the Productus limestone. C. L. Griesbach[1] who first described the fauna of the *Otoceras* beds of India, referred them to the Lower Trias, in which he has been followed by Wilhelm Waagen[2] and Carl Diener.[3] These writers consider the lower part of the Ceratite formation to be younger than any known Permian, and older than any fauna described from the European Trias, but they regard the affinities of the species as closer to known Mesozoic types, and the beds were considered as homotaxial with the lower part of the Werfen sandstone, the base of the Trias in the Mediterranean region. Now since this part of the Mediterranean section is barren of fossils, this correlation is based entirely on the stratigraphic position of the Ceratite formation.

C. Diener[4], in describing the fauna of the *Proptychites* beds of Ussuri Bay in eastern Siberia, correlated them with the *Otoceras* beds of India, because of the occurrence of several species common to the two regions. It is, therefore, evident that while the correlation of the Ceratite formation of India with the *Proptychites* beds of Siberia and the *Meekoceras* beds of western America may be accepted as correct, the final determination of the age of these beds depends entirely on a comparison with the type of the Lower Trias, the Buntsandstone of Germany, and the Werfen beds of the Alps.

In spite of the weakness of this argument, the Ceratite formation of India has until recently gone unquestioned as the type of the strictly marine equivalent of the Lower Trias, and all

[1] Records Geol. Surv. of India, Vol. XIII, 1880. Paleontological Notes on the Lower Trias of the Himalayas, p. 94.

[2] Mem. Geol. Surv. India, Pal. Indica, Ser. XIII. Salt Range Fossils, Vol. II. Fossils from the Ceratite Formation.

[3] *Ibid.*, Ser. XV. Himalayan Fossils, Vol. II, Part I. Cephalopoda of the Lower Trias.

[4] Mem. Com. Geol. St. Petersbourg, Vol. XIV, No. 3. Triadische Cephalopodenfaunen der Ostsiberischen Küstenprovinz.

correlations of the marine beds have been made by comparison with it. During the last year F. Noetling,[1] paleontologist of the Geological Survey of India, has startled geologists in their fancied security, by the statement, based on his later investigations, that the *Otoceras* beds of India belong to the upper Permian, and are older than the Werfen beds of the Alps. As they lie conformably upon the upper Productus limestone, they represent, according to Noetling, strata of which the equivalents are lacking in the European section. Accordingly he proposes to call the entire Ceratite formation upper Permian, and as a name for the stage he proposes the term Bactrian. If this should prove to be correct it would throw the Ceratite formation of India, the *Proptychites* beds of Siberia, and the *Meekoceras* beds of Idaho and California into the upper Permian.

A. von Kraft,[2] also of the Geological Survey of India, agrees with Noetling, but only as to the Permian age of the *Otoceras* beds; the upper part of the series where *Meekoceras* and *Flemingites* are so abundant he regards as certainly of lower Triassic age. He says that *Medlicottia dalailamae* Diener of the *Otoceras* beds is identical with *M. wynnei* Waagen of the upper Productus limestone, and that *Cyclolobus oldhami* Waagen and *Xenaspis carbonaria* Waagen, which in the Salt Range occur in the middle Productus limestone, in the Himalayas occur in the Kuling Productus shales only twenty or thirty feet below the *Otoceras* beds. This would make the bottom of the *Otoceras* beds (the lower Ceratite limestone) the equivalent of the upper Productus limestone of the Permian. This argument, however, might work both ways, for it would just as well prove that the upper Productus limestone belonged to the base of the Trias, since in any case the division line must be arbitrary. Nor would the finding of *Productus* itself in the *Otoceras* beds prove them to be

[1] Geol. Surv. of India, General Rept. for 1899 (1900). Notes on the Relationship between the Productus Limestone and the Ceratite Formation of the Salt Range, and Neues Jahrbuch für Min. Geol. und Pal., 1900. Bd. I, p. 139, Ueber die Auffindung von Otoceras sp. in der Salt Range.

[2] Centralblatt für Min. Geol. und Pal. Bd. II, 1901, p. 275, Ueber das Permische Alter der Otoceras-Stufe des Himalyas.

Paleozoic, for if *Otoceras*, *Medlicottia*, *Xenodiscus*, and *Xenaspis* can range into the Mesozoic, there is no known reason why *Productus* should not have done so. Indeed, *Xenaspis* and *Xenodiscus* range up into the Middle Trias, associated with faunas characteristic of the Muschelkalk.

C. Diener[1] meets Noetling's argument by stating that if the Ceratite formation of India is not of Lower Triassic age, then we have nowhere in the world a strictly marine equivalent of the Werfen beds, and that we have the anomaly of Middle Triassic beds lying conformably on Permian. He shows that the marine Permian of the Alps, which lies below the Werfen beds, has not the fauna of the *Otoceras* beds, but one analogous to that of the *Productus* limestone. Diener admits that the *Otoceras* horizon is older than the fossilferous portion of the Werfen beds, but thinks that the rule of priority of reference must be followed, where there are no paleontologic grounds against it and many for it. He also cites a recent paper by A. Bittner[2] to show that there is found in the *Proptychites* beds of Ussuri a typical pelecypod and brachiopod fauna of Werfen character; it must be admitted, however, that this fauna was not found with the ammonites, and might belong considerably above them.

The most direct comparison with the European Trias has been made by Lukas Waagen,[3] who shows that in the Ceratite marls and the Ceratite sandstone of India he has identified a number of pelecypods identical with forms characteristic of middle and upper Werfen beds of the Alps. This leaves the question about as A. von Kraft stated it. The Ceratite formation, from the Ceratite marls up, certainly belongs to the Lower Trias, since the Werfen beds are the type, while the *Otoceras* beds of the Himalayas, or their equivalent, the lower Ceratite limestone, may belong to the upper Permian. But the fauna of

[1] Centralblatt für Min. Geol. und Pal. Bd. I, 1900, p. 1, "Ueber die Grenze des Perm- und Triassystems, etc."

[2] Mém. Com. Geol. St. Petersbourg, Vol. VII, 1899, "Verstein. aus den Trias-Ablagerungen des Süd-Ussuri Gebietes in der Ostsibirischen Küstenprovinz.

[3] Centralblatt für Min. Geol. und Pal. Bd. I, 1900, p. 285.

the lower Ceratite limestone and that of the Ceratite marls are so similar that a separation of the two is out of the question, and even the genus *Otoceras* is found in the latter. Now, since these doubtful beds are younger than any accepted Permian, and older than any authentic Trias, they might with equal propriety be assigned to either, and we shall have to extend one or the other system to include them. The question will have to be decided either by paleontologic relationship, or by priority of reference. The *Otoceras* beds contain *Meekoceras*, *Proptychites*, *Ophiceras*, and several other ammonite genera that have never been found in the Paleozoic; they contain also *Medlicottia* and *Otoceras* that are more characteristic of Upper Permian; but they lack the Productidae and Orthidae that characterize the Permian formation. Thus the paleontologic evidence is about equal in favor of a reference to either Paleozoic or Mesozoic. But the geologists that described the fauna of the doubtful beds have almost unanimously referred them to the Lower Trias, and this must be the final verdict.

The fauna of the *Meekoceras* beds of Idaho and California is most intimately related to that of the Ceratite marls and the lower part of the Ceratite sandstone of India, with most of the genera in common, and several species that seem to be identical. And although the writer has searched carefully for *Otoceras* in both places, no trace either of this genus or of *Medlicottia* was found. It seems likely, then, that even if the bottom of the Ceratite formation should be cut off from the Trias and assigned to the Permian, this change would not affect the nomenclature of our American formations that are now considered as the bottom of the Mesozoic series, and the *Meekoceras* beds will stand as the type of the marine Lower Trias, where White and Hyatt placed them in 1879. The real transition from Paleozoic to Mesozoic must be sought in the conformable series below the *Meekoceras* beds, and above the *Fusulina* limestone.

JAMES PERRIN SMITH.

STANFORD UNIVERSITY,
California.

Studies for Students

THE CONSTITUENTS OF METEORITES. II

Glass.—This is an abundant constituent of the stone meteorites, few if any being entirely without it. It is variously distributed, occurring now as vein matter, now scattered through the substance of chondri, now enclosed in the substance of a single mineral, and now enclosing various minerals.

In the Parnallee, Mezo-Madaras, Chassigny, Farmington and a few other meteorites it has been described as forming a network in which the other minerals are imbedded. Its ocurrence in this manner is rare, however, it playing usually a merely accessory part. It chiefly abounds as inclusions and intergrowths in chrysolite, taking in this association a great variety of forms. Other minerals too, frequently have inclusions of glass. It may occur in fragments of considerable size or the particles may be of a dustlike minuteness.

Its abundance in chondri has already been mentioned. By all these occurrences a rapid crystallization or cooling of the meteorite substance is strongly indicated. Like the glass of terrestrial lavas it seems to be the result of cooling so rapid as to prevent differentiation and orderly crystallization of the magma. The especial abundance of glass in meteoritic chrysolite, the least fusible and therefore the earliest cooling ingredient further favors this conclusion.

The prevailing color of the glass of meteorites is brown. Much is however colorless and some occurs so dark as to be opaque. Grayish and greenish tones occur but are rare.

Chromite.—Nearly all stone meteorites give on analysis a small percentage of chromium which is usually considered as being present in the form of chromite, FeO,Cr_2O_3. The mineral is not so abundant in the iron and iron-stone meteorites

but has been detected in several and in the Coahuila irons occurs in nodules of considerable size ($17^{mm} \times 12^{mm}$).

It is identical with terrestrial chromite in composition and properties. Not being acted upon by acids, it may be readily distinguished from daubréelite. It is generally non-magnetic, but sometimes feebly magnetic. Where crystals occur they are commonly octahedrons, sometimes modified by other forms.

Amorphous carbon.—Meteorites of the group known as carbonaceous meteorites, as well as some others, are permeated by a dull-black pulverulent coloring matter which is usually left as a residue on treatment of the meteorite with acid. This residue sometimes amounts to from 2–4.5 per cent. of the mass.

A residue similar in character though smaller in amount is likewise found after dissolving many of the iron meteorites. These residues on being heated in air glow, usually become lighter in color and give off carbon dioxide. They must therefore be considered practically pure carbon.

Berzelius and Wöhler believed this carbon to have originated so far as the carbonaceous meteorites are concerned, from the decomposition of the hydrocarbons of the latter. In this respect they regarded it analogous to terrestrial humus, though of very different origin. Smith considered it similar in origin to the graphite of iron meteorites and Weinschenk believes it similar to one of the forms of carbon produced in the making of cast iron. No indications that it had an organic origin have ever been discovered.

Diamond.—The existence of diamonds has been definitely proven in only two meteorites, those of Cañon Diablo and Nowo-Urei. Diamonds have, however, also been reported from the irons of Magura and Smithville and the stone of Carcote. The diamonds of the Cañon Diablo meteorites have been most studied. Here they are found as minute particles or dust left as a residue after dissolving the meteorite in acid. The particles rarely exceed $\frac{1}{2}^{mm}$ in diameter. They are usually brown to black in color but sometimes are colorless and transparent. They accompany graphite, amorphous carbon and often troilite

and schreibersite. They have a tendency to gather in little clefts or hollows and are not regularly distributed. Their character as diamond is proven chiefly by their hardness, but analyses and a study of their behavior in polarized light give confirmatory results. Huntington found some also which showed crystal forms of diamonds. The occurrence of diamonds in meteorites suggests interesting analogies with their terrestrial occurrence. Knop and Daubrée call attention to the fact that the peridotic rocks in which terrestrial diamonds occur are the rocks most nearly allied in composition to meteorites. In the iron meteorites, as Moissan has proven satisfactorily by experiment, diamond is to be considered a form in which, under certain conditions of heat and pressure, carbon separates. Moissan obtained diamonds by heating to a high temperature iron saturated with carbon and allowing it to cool under pressure. The carbon was then found to exist in three forms, graphite, foliated carbon, and a diamond powder which latter corresponded to that obtained from the Cañon Diablo meteorites.

A form of carbon resembling graphite but differing in having a hardness of 2.5 and being isometric in crystallization, has been noted in the Magura, Cosby's Creek, Youndegin, Toluca and a few other iron meteorites. It was first discovered by Fletcher, who considered it a distinct species and gave it the name cliftonite. Other authorities, however, regard cliftonite as a pseudomorph after diamond, since its crystals closely resemble those of diamond in form.

Daubréelite.—This mineral is an iron-chromium sulphide peculiar to meteorites. Its composition is $Fe\,S, Cr_2\,S_3$. It is found in nearly all the cubic iron meteorites and has also been identified in the irons of Toluca, Nelson county, Cranbourne, Cañon Diablo and others. It has never been found in stone meteorites. It usually accompanies troilite, either bordering nodules or crossing them in veins. Sometimes, however, it occurs as thin plates or grains. It is black in color, has a black streak, is of metallic luster, brittle and not magnetic. It is infusible before the blowpipe and becomes magnetic in the reducing flame. It is not

attacked by hot or cold hydrochloric acid, but is completely dissolved by nitric acid without the separation of free sulphur. This solubility distinguishes it from chromite. Its system of crystallization is not known though it exhibits rectangular and triangular partings which indicate one of the systems of high symmetry. Meunier obtained the mineral artificially by treating an alloy of iron and chromium at a red heat with hydrogen sulphide.

Tridymite.—This mineral has been positively identified in only one meteorite (Steinbach), but it probably also occurs in the Vaca Muerta and Crab Orchard Mountains meteorites. These are all ironstone meteorites. In the Steinbach meteorite it forms from 8.5 to 33 per cent. of the non-metallic constituents and occurs intergrown with bronzite.

Maskelyne, who first described the mineral, considered it on account of its optically biaxial character a new orthorhombic form of silica and gave it the name of asmanite. Since tridymite is now known, however, to exhibit biaxial characters and the minerals agree in most other respects, they are generally considered identical.

Tridymite occurs in meteorites in the form of rounded grains or plates, some of which reach a length of 3^{mm}. They are colorless to white to rusty brown in color.

Well developed crystals are rare but from facets on rounded grains a total of twelve forms has been determined.

Analyses show a composition of practically pure silica, with iron oxide and magnesia present as impurities.

Lawrencite.—This is a solid ferrous chloride which has been described from the iron meteorites of Tazewell, Smith Mountain, and Laurens county. Formula $Fe\,Cl_2$. Color green to brown. While described in the solid form from only the few meteorites mentioned, the presence of lawrencite in many other iron meteorites is generally believed to be indicated by the greenish drops which exude on their surfaces. These drops are ferric chloride or mixtures of ferric and nickel chloride, while occasionally pure nickel chloride occurs.

The meteorites from which ferric chloride exudes disintegrate with especial rapidity. Such meteorites are often known as "sweating" meteorites. The "sweating" is rarely noted in ironstone or stone meteorites, but the small percentage of chlorine found in the analysis of many of these meteorites is usually referred to lawrencite. Some authorities hold that the substance is not an original constituent of any meteorite, but is wholly of terrestrial origin. This is not the general opinion however.

Ferrous chloride has been noted among the sublimation products at Vesuvius and is reported as having been found in the terrestrial nickel-iron of Ovifak.

Magnetite.— Several stone or ironstone meteorites have been found to contain black, magnetic grains which dissolve in hydrochloric acid without effervescence to form a yellow solution.

In the meteorites of Shergotty and Doña Inez these are sufficiently abundant to form an essential constituent. They constitute 4.57 per cent. of the Shergotty meteorite. Similar grains occur as inclusions in maskelynite, pyroxene, and chrysolite in the above and other meteorites. They are regarded as magnetite.

No well marked crystals of meteoritic magnetite have as yet been described.

Magnetite has been reported as a constituent of several iron meteorites though only one analysis has been made, that of Meunier of magnetite from the crust of one of the Toluca irons. The composition of this agreed with that of terrestrial magnetite. Several other iron meteorites show magnetite in their crust. Here, however, the magnetite may have originated from the oxidation of the iron of the mass since its arrival upon the earth.

Magnetic spherules have been dredged up from ocean depths, which Murray and Renard regard as particles of meteoric iron oxidized to magnetite since their arrival upon the earth.

Oldhamite.—This is a simple calcium sulphide with the formula $Ca\ S_2$. Grains of it were found by Maskelyne embedded in the enstatite or augite of the Bustee meteorite. It is light

brown in color and transparent when pure. Hardness 4, specific gravity 2.58. It is isotropic and has equal cleavage in three directions, hence is doubtless isometric. In the Bustee meteorite it occurs in rounded grains, coated with gypsum through alteration.

Certain yellow grains found in the Bishopville meteorite were also considered by Maskelyne to be this mineral. Aside from these two occurrences it has not been positively identified in any other meteorite.

Calcium sulphide resembling oldhamite was obtained by Maskelyne by heating caustic lime in a glass tube, first with hydrogen, then with hydrogen sulphide. Vogt has noted a similar compound formed in furnace slags.

It has not been found as a terrestrial mineral.

On dissolving the oldhamite of the Bustee meteorite, Maskelyne found a residue constituting about 0.3 per cent. of the weight of the former, consisting of yellow octahedrons of microscopic size. These were found to be unaffected by acids or oxygen, while qualitative tests indicated sulphur, calcium, and titanium or zirconium. Maskelyne regarded the mineral therefore an oxysulphide of calcium and titanium and gave it the name osbornite. No other occurrence of the mineral is known.

Hydrocarbons.—The hydrocarbons found in meteorites may be divided, following Cohen,[1] into three classes: (*a*) compounds of carbon and hydrogen; (*b*) compounds of carbon, hydrogen and sulphur; and (*c*) compounds of carbon, hydrogen and oxygen. They especially characterize meteorites of the class known as carbonaceous, which includes seven or eight distinct falls of meteorites of black color, low specific gravity and containing a sensible amount of carbon. They have been obtained from some other meteorites however, such as those of Collescipoli and Goalpara. The hydrocarbons of the first class are obtained by treating these meteorites with alcohol or ether. They are resinous or wax-like bodies which completely volatilize on the application of heat. When heated in a closed tube the resinous substances first fuse,

[1] Meteoritenkunde. Heft. I, p. 159.

then are decomposed to form amorphous carbon and an oil hav-a bituminous or fatty odor. Such substances were considered by Wöhler similar to the mineral wax ozocerite and by Shepard they were designated meteoritic petroleum. Friedheim states that a substance extracted by him from the meteorite of Nagaya by means of ether had a bituminous odor, volatilized at 200° and resembled a product of distillation of brown coal. A similar substance extracted by Roscoe from the meteorite of Alais was found to have a composition corresponding nearly to the formula $C\,H_{2n}$.

Hydrocarbons of the second class were obtained by Smith by treating the graphite of iron meteorites and some carbonaceous meteorites with ether. These compounds were fusible and volatile. He regarded them as having the general composition $C_4H_{12}S_5$. He obtained similar products by treating cast iron with ether or petroleum as did also Berthelot by the action of ether on sulphur or iron sulphide in the presence of oxygen.

Hydrocarbons of the third class have been obtained from the meteorites of Orgueil and Hessle. The Orgueil extract resembles peat, humus or lignite in its composition and properties. That from Hessle has approximately the composition $n\,C_9H_8O_2$.

The above mentioned facts make it clear that a number of meteorites contain products of an easily destructible, volatile, and combustible character which resemble terrestrial bitumens, petroleum or oxygenated hydrocarbons. The quantity of these products is relatively small, being less than 1 per cent. in the majority of meteorites in which they occur. Yet that they occur at all is significant. While some have urged that these products might have arisen from the union of their elements in the terrestrial atmosphere there seems little reason for doubting their pre-terrestrial origin. There is no evidence that life had anything to do with their origin. We must conclude then that they were formed in an inorganic way by a union of their elements. The conclusion at once suggests the possibility that

terrestrial hydrocarbons need not always be referred to an organic origin, but may have been formed in a purely inorganic way.

The occurrence of hydrocarbons in meteorites further shows that such meteorites could not have been subjected to any high degree of heat subsequent at least to the formation of these compounds, and that the heating of meteorites during their fall to the earth has in many cases been only superficial.

The trails of light, sometimes enduring several minutes, observed following in the wake of some meteors may perhaps indicate the presence of carbonaceous matter in those bodies. The stone shower which took place at Hessle was accompanied by luminous effects and with the stones fell a brownish-black powder which contained 71 per cent. carbonaceous matter. Other carbonaceous meteorites have fallen, however, without exhibiting any marked luminous phenomena.

Other compounds.— Besides the above well-determined compounds a number of others have been reported at different times which are (1) present in insignificant amount or (2) their occurrence has not been confirmed, or (3) they may be of terrestrial origin. Among these a few may be mentioned: *Quartz.* This mineral, as is well known, is remarkable for its absence from meteorites. Yet it doubtless does occur in minute grains in a number of iron meteorites, since on dissolving them a residue is left, the grains of which possess the properties of quartz. Its occurrence in any stone or ironstone meteorite has never yet been established. *Pyrite.* This mineral has been reported a number of times, but sufficient proof to establish its identity has not been given. Von Siemaschko reported from the meteorite of Ochansk a brass-yellow pentagonal dodecahedron of which, however, he gave no measurements. Daubrée found in the meteorite of Senhadja, bronze-yellow grains insoluble in hydrochloric acid, soluble in aquaregia and altering easily to iron sulphate. While these and other observations suggest pyrite they are not conclusive. *Salts soluble in water.* Several of the carbonaceous meteorites as well as one or two others give

on evaporation of the water extract a residue of soluble salts reaching in quantity in one case as high as 10 per cent. of the mass. These salts include nickel, calcium, magnesium, potassium, sodium and ammonium sulphates and chlorides.

Since the meteorites in which they occur are very porous in character and show other signs of alteration these compounds are usually considered to be formed by terrestrial modification of the meteorite and not to exist as original constituents. Daubrée, however, gives good reasons for regarding the sodium chloride which he found in the Lancé meteorite an original constituent. These reasons are that the meteorite had lain only three days in a clayey bed before it was picked up and no salt is known to have come near it. *Breunnerite.* This mineral was found in the meteorite of Orgueil occurring in the form of little transparent crystals. The identity of the mineral was established both by qualitative tests and by goniometric measurements. It has been suggested that it was of secondary origin. As it was found well within the interior of some masses, this, however, hardly seems likely. This is the only carbonate known from meteorites.

A number of other minerals have been reported from meteorites without sufficient grounds, according to the writer's view, to support the conclusion. Cohen considers them doubtful while Meunier accepts most of them. These are: *Apatite*, *iolite*, *wollastonite*, *titanite*, *garnet*, *vesuvianite*, *mica*, *aragonite*, *leucite*, *cassiterite*, *hornblende*, *anthophyllite and orthoclase.*

Mineral aggregates.—The different aggregates which the compounds above described form in different meteorites are too various to be recorded here in detail. For an account of these, reference should be made to the elaborate classifications of Meunier,[1] Brezina[2] or Wülfing.[3]

A few general observations may be made here, however, following the lines of the classification given by Wülfing. The

[1] Revision des Pierres Météoriques. Paris, 1897.

[2] Annalen des k. k. Naturhistorischen Hofmuseums. Bd. X, Heft 3 u. 4. Vienna, 1896.

[3] Die Meteoriten in Sammlungen. Tübingen, 1897, pp. 447–460.

iron-meteorites, as already indicated, are made up chiefly of nickel-iron, with schreibersite, troilite, daubréelite and a few other minerals occurring as accessories.

Of the ironstone meteorites the largest quantity are of the so-called pallasites, formed chiefly of chrysolite and nickel iron. Nine falls of this group are known, having a weight of 1742 kilograms. In the group known as siderophyrs, represented by one fall (82 kilos), of meteoritic matter, bronzite and tridymite are associated with the nickel-iron. In the group of mesosiderites (grahamites) represented by ten falls (483 kilos), of meteoritic matter, the nickel-iron is accompanied by chrysolite, bronzite, plagioclase, and augite. In the group lodranite, composed of one fall with a weight of 1 kilo, chrysolite and bronzite are associated with nickel-iron.

Passing to the stone meteorites the following groups and weights may be noted:

A. Stones rich in calcium and magnesium and containing little or no nickel-iron.

1. Angrite. Chiefly augite. One fall, weight 0.4^{kg}.
2. Eukrite. Augite and anorthite. Four falls, weight 91^{kg}.
3. Shergottite. Augite and maskelynite. One fall, weight 5^{kg}.
4. Howardite. Augite, anorthite, bronzite, and chrysolite. Ten falls, weight 5^{kg}.

B. Stones rich in magnesia and containing little or no nickel-iron.

1. Bustite. Diopside and bronzite. Two falls, weight 1.7^{kg}.
2. Chassignite. Chiefly chrysolite. One fall, weight 0.9^{kg}.
3. Chladnite. Chiefly orthorhombic pyroxene. Four falls, weight 9^{kg}.
4. Amphoterite. Chiefly chrysolite and bronzite. Three falls, weight 40^{kg}.

C. Stones rich in magnesia and consisting essentially of chrysolite, bronzite, nickel-iron, and iron sulphide. Here belong the great majority of stone meteorites.

A comparison of the constituents as above described with those of the crust of the earth brings to view some interesting similarities and contrasts. Under *similarities* may be noted the fact that the elements of meteorites are the same as those of the earth and that they unite according to the same chemical and physical laws. No new element has been discovered in meteorites and the chemical compounds of meteorites similar to those of the earth agree even to the details of their crystal form.

Under *contrasts* it may be noted that two agents which have affected largely the composition of the crust of the earth have been lacking either wholly or in part in the formation of meteorites. These agents are water and oxygen. The lack of water is proved by the fresh and unaltered character of the minerals found in meteorites and the absence of all hydrous minerals. Thus the chrysolite of meteorites is never found serpentinized nor are the pyroxenes changed to chlorite nor the feldspar to kaolin.

Further, zeolites, micas, epidote, tourmaline and all other minerals in the formation of which water and water vapor play a part are entirely lacking from meteorites.

Similarity, oxygen, at least in excess, is lacking from the constituents of meteorites. Such substances as nickel-iron, schreibersite, and lawrencite, which make up so large a part of the composition of meteorites would rapidly have been oxydized had they been exposed to the action of oxygen as it occurs upon the earth. The silicates of meteorites are however oxydized compounds which show that oxygen is present to some degree in space.

Again, as noted by Cohen,[1] the important rock-forming minerals of the crust of the earth are either lacking or play an insignificant part in the formation of meteorites. Such are quartz, orthoclase, the acid plagioclases, the micas, the amphiboles, leucite, and nepheline. Vice versa, the chief mineral constitutents of meteorites occur in but insignificant amount upon the earth. Such are nickel-iron, the orthorhombic pyroxenes and chrysolite, while such compounds as schreibersite, cohenite, lawrencite, oldhamite, daubréelite and troilite rarely or never occur terrestrially. Looked at quantitatively then it may be said that terrestrial rocks abound in free silica, lime, alumina, and alkalies, while meteorites abound in iron, nickel and magnesia. Whether these quantitative differences would be maintained if the constitution of the earth as a whole could be compared with that of meteorites, is, as hinted at the beginning, doubtful.

OLIVER C. FARRINGTON.

[1] Op. cit., p. 323.

Among the innumerable phases of the great calamity which has fallen upon our country and the world in the tragic death of President McKinley, the loss of a generous friend of science is by no means the least. The prosperity of the scientific bureaus under his administration has been as marked in improved organization and in method as in extension and in generous patronage, and the establishment of a new bureau in the interest of scientific and commercial precision is a laudable feature of special moment.

EDITORIAL

In December, 1898, Mr. G. K. Gilbert presented to the Geological Society of America a paper upon ripple-marks and cross-bedding in which he undertakes to explain the large ripples of the Medina formation.[1] Mr. Gilbert became satisfied that these ripples differ "in no respect except size from the familiar ripple-mark of the bathing beach and the museum slab." In order to account for the size of some of the large ripples upon this theory he has inferred that the waves producing them were sixty feet high and made in "a large ocean."

In the July number of the *American Geologist*, Professor H. L. Fairchild objects to the deep ocean theory of the origin of these ripples, and brings evidence to show that they are beach structures.[2]

Without going into the details of either of the articles mentioned the present writer wishes to call attention in this connection to a paper upon the origin of beach cusps published in this JOURNAL (September–October, 1900, Vol. VIII, pp. 481–484), and to suggest that the explanation of the giant ripples spoken of by Gilbert and Fairchild is to be found in the seaward extension of beach cusps. The beach cusps are from sixty to eighty feet apart, from a few inches to three feet in vertical height and extend oceanward in approximately parallel lines. They are formed by the interference of two sets of waves of translation, and are therefore to be looked for not only on the beach where they appear at the water's edge, but as far out as the waves drag upon the sea bottom, and always pointing away from the shore. This theory appears to account readily for all

[1] Ripple-marks and Cross-bedding, by GROVE KARL GILBERT. Bull. Geol. Soc. Amer. Vol. X, pp. 135–140.

[2] Beach Structures in Medina Sandstone, by H. L. FAIRCHILD. Amer. Geologist, Vol. XXVIII, pp. 9–14.

the phenomena observed in connection with the ripples in the Medina without doing violence to the theory of the shallow water origin of those beds.

J. C. Branner.

The experiment of holding the summer meeting of the American Association for the Advancement of Science as far west as Denver may be regarded as a success. The attendance compared favorably with what has previously been realized at several meetings in the interior, though for obvious reasons it was less than the attendance at meetings held in the more populous and accessible centers of the East. The papers and discussions, so far as one could judge from listening to those of a single section and from current opinion, also compared favorably with those of average meetings. There was less diversion from the specific purposes of the association by formal social functions which were few, and there was correspondingly greater real social intercourse between fellow scientists, because the intersessional intervals were more largely left free for this, a most laudable feature. The provisions for scientific excursions, at least in geologic lines, were notably more ample than usual and were arranged for the afternoons of the regular session, the morning sessions being extended to make this possible. The facilities for general and varied excursions at the close of the formal sessions were exceptionally generous. Only one feature of the general appointments and of the environment needs to be singled out for adverse comment, and that was the dreary silliness of the Denver press which, apparently recognizing its limitations in reporting appreciatively and intelligently the real scientific news, tried to make up for its inabilities by stale witticisms and coarse cartoons, interspersed with extravagant personal laudations of "the-greatest-scientist-on-earth" type. A few subjects relating to the economic interests of the region and to popular themes were, however, well reported.

The general addresses were excellent; that of retiring-President Woodward was an incisive and discriminating discussion of the progress of science, graced with an artistic marshaling

of lights and shadows as wholesome as it was skilful; that of Vice-President Van Hise on the philosophy of ore deposition was clear, strong and effective, and especially laudable, as a popular address in a mining region, for its unhesitating advocacy of the unpalatable as well as the acceptable phases of his doctrine.

Previous to the meeting a ten-day excursion of geologists was planned by Professors Van Hise and Emmons and carried out in a most admirable manner. The selection of routes and places from among the phenomenal possibilities of Colorado certainly made no small demands upon the knowledge and discretion of those in charge, but no whisper of a possible improvement was heard. The climax of interest was reached in the San Juan Mountains, where the exemplification of many and varied phases of geological phenomena from the Archean to the Pleistocene is marvelously impressive. The aid rendered by prominent citizens at various points visited and the generous hospitality extended to the party were beyond all praise. It would be a delight to acknowledge our obligations in special and individual terms, if, beginning with the exceptional courtesies of Walsh, Lay, and Freeland, it were possible to find an end of the list. About two dozen geologists participated.

The four geological sessions were crowded with papers well distributed over the various departments of geology and embodying much of exceptional interest and value. The papers read before the Geological Society of America, presented on the first morning, were as follows: "Account of the Geological Excursion," C. R. Van Hise; "Junction of the Lake Superior Sandstone and the Keweenawan Traps in Wisconsin," U. S. Grant; "Hydrographic History in South Dakota," J. E. Todd; "The Still Rivers of Western Connecticut," W. H. Hobbs; "Geology of the Northeast Coast of Brazil," John C. Branner; "Classification of the Geological Formations of Tennessee," James M. Safford; "Horizons of Phosphate Rock in Tennessee," James M. Safford.

The following papers were presented before Section E:

"The Effect of Diurnal Heat on Glacial Activity," J. F. Todd; "On Extra Terrestrial Stresses," E. Haworth; "On Stoping as a Factor in the Formation of Terraces," T. C. Chamberlin; "On Campodus, Helicoprion, Acanthus and other Paleozoic Sharks," Charles R. Eastman; "The Oscillations of the Coast Ranges of California," A. C. Lawson; "Some Features of the Geology of Golden, Colorado," H. B. Patton; "The Geological Occurrence of Oil in Colorado," A. Lakes; "Report on Some Studies Relative to Primal Questions in Geology," T. C. Chamberlin; "A Plea for Greater Simplicity in the Language of Science," T. A. Rickard; "Sandstone Intrusions near Santa Cruz, California," J. F. Newsome and J. C. Branner; "On the Pleistocene Deposits of Iowa," Samuel Calvin; "Problems of the Quaternary Deposits of the South Platte Valley," George L. Cannon; "Physiography of the Boston Mountains, Arkansas," A. H. Purdue; "Some Problems of the Dakota Artesian System," James E. Todd; "A Quantitative Study of Variation in the Fossil Brachiopod Platystrophia biforta, Schl.," E. R. Cumings and A. V. Mauck; "Interpretation of Some Drainage Changes in Southwestern Ohio," W. G. Tight; "The Minerals and Mineral Localities of Texas," F. W. Simonds; "The Minerals Associated with Copper in Southeastern Arizona and Southwestern New Mexico," G. H. Stone; "The Extinct Glaziers of New Mexico and Arizona," G. H. Stone; "Note on Certain Copper Minerals," A. N. Winchell; "The Areal Geology of the Castle Rock Region," W. T. Lee. The officers of the section were: C. R. Van Hise, vice president, and H. B. Patton, secretary. Those elected for the ensuing year are: O. A. Derby, of San Paulo, Brazil, vice president; and F. P. Gulliver, of Southboro, Mass., secretary.

C.

Reviews

THREE PHASES OF MODERN PALEONTOLOGY

I. *Uintacrinus: Its Structure and Relations.* By FRANK SPRINGER. (Mem. Mus. Comp. Zoöl., Vol. XXV, pp. 1–90, 8 pls., Cambridge, 1901.)

II. *Oriskany Fauna of Becraft Mountain.* By JOHN M. CLARKE. (Mem. New York State Mus., Vol. III, No. 3, 128 pp., 9 pls., Albany, 1900.)

III. *Stratigraphical Succession of the Fossil Floras of the Pottsville Formation in the Southern Anthracite Coal Field.* By DAVID WHITE. (U. S. Geol. Surv., Twentieth Ann. Rept., Part II, pp. 749–930, 13 pls., Washington, 1901.)

Three notable contributions to our knowledge of fossil organisms have lately appeared from the hands of the printer. They are notable as making distinct advancements in paleontology. They are notable as typifying the three distinct phases into which the science relating to ancient life has finally resolved itself. They are notable as model works of their kind, each representing the general subject from a very different viewpoint, and hence show very diverse modes of treatment and the very diverse character of paleontological inquiry of today.

1. The crinoids have long been an attractive theme to geologists. Ever since the discovery by Marsh, in 1870, of the remarkable Cretaceous crinoid afterward called Uintacrinus, great interest has been taken by paleontologists in each new accession. Grinnell, Meek, Willison & Hill, and Logan, in this country, and in Europe, Schlüter and Bather, have described carefully the known material. It has remained for Mr. Springer, so long intimately associated with the lamented Wachsmuth, to give us a magnificent monograph on the subject, including a large amount of new information derived from rich, lately discovered material. And this after one would naturally think that about all that it was possible to say had been said.

The special charm and value in this work is the strictly morphological character that it presents. In this respect it fully keeps up the

same high standard of excellence that made the *North American Crinoidea Camerata* of Wachsmuth & Springer so acceptable to all students of fossil organisms.

Unusual interest centers in the composition of the base of Uintacrinus. A feature that has long been regarded as fundamental in the separation of the larger taxonomic groups is here found in one and the same species. "Considering the apparent identity of these forms in every other point of structure, coupled with their mode of occurrence and association, I do not see how such association [as made by Mr. Bather] can possibly be made in this case. We therefore have apparently to deal with a case of individual variation as to this supposed primitive character, within the limits of a species. That is to say, in this species, living in the same locality, having the same environment, floating in the same mass, certain individuals matured to represent one stage of larval development, *i. e.*, with infrabasals; and others in another stage, *i. e.*, with basals only.

In short, there are the two supposed distinct types, Monocyclica and Dicyclica, occurring in both young and adult of one and the same species. It will not do to say that the species is dicyclic, but in certain individuals the infrabasals are not developed, or are hidden by the centrale, or have disappeared by atrophy, If this were so, the centrale ought to be interradial in both cases; whereas, as already shown, its orientation is reversed from one to the other, precisely as in the typical monocyclic and dicyclic forms.

Such a condition is believed to be unique among the crinoids. The bearing upon certain recently proposed classifications of the crinoids is also important. Bather and Jaekel have both severely criticised Wachsmuth & Springer's classification and have erected schemes that are "sought by the modern biologist."

"There is no doubt," says Mr. Springer, "that each author who undertakes to express his ideas of descent in a new scheme of classification does so in the belief that his own structure is a substantial pyramid whose base is firmly established upon the ruins of the top-heavy contrivances of his predecessors. With regard to the crinoids, there have appeared, since our monograph of the Camerata, two elaborate classifications, each avowedly based upon phylogenetic principles, viz., that of Mr. Bather, already mentioned, and one by Dr. Jaekel, whose general researches and great works upon the crinoids of Germany constitute a rich contribution to science. The views of the latter author are to be developed in full detail in his magnificent

"Stammesgeschichte der Pelmatozoen," the first part of which, embracing the Thecoidea and Cystoidea, has just been published. He, likewise, finds fault with Wachsmuth & Springer, because, in his opinion, they have dealt with the morphological conditions as they found them too much from an anatomical standpoint, and have not sufficiently taken into account the import of the modifications due to descent. He finds in the changes in the systematic arrangement of the crinoids made by Wachsmuth & Springer in their successive writings, proof that the right road to the solution of the great questions of classification had not yet been found. We have, therefore, two new and almost simultaneous phylogenetic classifications, by two of the most eminent living authorities, both predicated in part upon the insufficiencies of Wachsmuth & Springer's system, and each believed by its author to be a new and correct reading of the race history of the crinoids. From such sources, and following such a preface, we should not unnaturally expect a brilliant illumination of the road, in search of which their predecessors have floundered in darkness. But to our dismay we find that instead of celebrating a conclusive settlement of these questions, we are only invited to witness fresh controversy. For these new chroniclers do not read their history alike, and their two classifications are about as diametrically and fundamentally opposite as anything could be."

Uintacrinus presents a striking resemblance to the living crinoid Actinometra in the eccentric position of its mouth, the central position of the anus, the absence of any calcified ambulacral skeleton on disk, arms and pinnules, the structure and distribution of the disk ambulacra, the form and proportions of brachials, and distribution of syzygies, the variable size of the anal tube, and the instability of the base.

The systematic position of Uintacrinus will be a matter of controversy for a long time to come. As yet hardly any two authorities agree in placing it in the same position.

Wherever it may belong, and whatever its line of descent, there is no doubt that Uintacrinus is both a protean and convergent form more remarkable than any we have hitherto encountered among the crinoids. Along with great variability in the base and interbrachial regions, it combines:

The interbrachial system and fixed pinnules of the Camerata;

The pliant test of the Flexibilia;

The large visceral cavity of both of these;

The exoclyclic disk and open ambulacara, and the arms, pinnules, and syzygies of Actinometra;

The free-floating character of the Comatulæ;

The dicyclic base of the Dicyclica;

The monocyclic base of the Monocyclica.

A noteworthy feature that should receive special mention in connection with this monograph is the distribution of study material, illustrating the points and structures discussed, to some of the principal museums. It is a feature that could well be imitated by other workers in paleontology. In this way the principal type specimens have been deposited in the Museum of Comparative Zoölogy. A large slab has been placed in the National Museum at Washington; it contains specimens exhibiting most of the characters discussed. A fine series of specimens have also been sent to the British Museum, and to the Royal Museum of Natural History at Berlin, where they will be accessible to European students.

2. As stated by Dr. Clarke, in his prefatory note to the *Oriskany Fauna of Becraft Mountain*, the original purpose of his work was solely to depict the character and composition of the Oriskany fauna of Becraft Mountain, which of itself displays many features of interest. In its progress, however, various questions have arisen which concern the intrinsic value of the fauna and its importance in correlation. Yet without an understanding of the fauna itself it would be impracticable to discuss the latter problems, and for this reason the title of the paper is restricted to the principal argument of the work, to which the discussions of a somewhat broader scope are corollaries.

A fauna which finds its highest development at Becraft Mountain, near Hudson, in Columbia county, N. Y., links together in the character of its species, the calcareous shales and limestones of the Lower Helderberg and the normal Oriskany sandstone.

The interesting bearings of this assemblage of species, its new forms and new associations and its real importance in the correlation of the Lower Devonian are sufficient reason for presenting its characteristics in detail.

A brief account of the stratigraphy of the mountain is given, and also the general New York section as recently revised. Accompanying these is a small geological sketch-map of the Becraft Mountain syncline.

The greater portion of the memoir is devoted to the description of species, which are finely illustrated by nine plates of figures. A table of the vertical range of species occurring in the region is given.

With our present knowledge there are thus 113 recognizable, distinct specific forms in the fauna of the Oriskany at Becraft Mountain, and of these 94 are identifiable with species already known or are clearly new forms peculiar to the fauna. Of the 94, 25 preceded the introduction of the Oriskany sedimentation, having been first described from the fauna of the Helderbergian. In the arenaceous beds of the Oriskany 23 occur; 10 range upward into the faunas of the Upper Helderberg (Ulsterian), but a part of these are restricted to the sandy, lower beds of this formation (Schoharie grit), and others have been noted only in the chert beds of Ontario, Canada, where the intermixture of Oriskany and Onondaga species is well marked and has been recorded by Schuchert. The fauna contains 35 species which so far as known are peculiar to it. On farther analysis of the table, it is evident in some cases that species which range down and upward are restricted to particular groups. Thus the alien trilobites are from the Helderbergian; the gasteropods are exclusively Oriskany; while the alien lamellibranchs are mostly Helderbergian. But the leading factor of the fauna, the brachiopod, has its derivation as freely from below as in the Oriskany invasion.

The faunal values of the different species are then summed up.

Concerning the nature of the Oriskany fauna of New York, the author says:

The fauna of the calcareous Oriskany is in no sense a mixed assemblage, or an intermingling of faunas of adjacent provinces. The sequence of life has continued without interruption from the Helderbergian (Kingston beds) into the sediments of the Oriskany and Onondaga limestone.

It is extremely probable that important variations from the fauna of the Catskill shaly (New Scotland) limestone had already made their appearance in the Becraft limestone, and that we first become acquainted with some of these in the study of the calcareous Oriskany. No proof therefore could be adduced more emphatically confirmatory of the intimate faunal relations of the Helderbergian with the Oriskany fauna and its successors than the facts brought forward in this paper.

The fauna discussed is that of the calcareous facies of the Oriskany formation. The sedimentary deposits of this and the neighboring sections were essentially limestones notwithstanding the silicious content, whether diffused through the mass or segregated as cherty secondary product. In the earlier presentation of this fauna it was regarded as of lower Oriskany horizon on account of the presence of many Helderbergian species, but we believe it will be more correctly construed as the representative of the proper and normal Oriskany fauna, the true fauna of this time-unit inclosed in the sediments of its proper habitat.

A chapter is devoted to discussing the Devonic age of the Helderbergian fauna and the base of the Devonic system in New York.

The fact of the presence of numerous Helderbergian species in the fauna of the Oriskany of Becraft Mountain, as an integral part of that fauna, not a casual intermixture, is sufficient demonstration that the fauna of the Helderbergian became modified in its continued existence by the departure or extinction of certain of its species only. A fair percentage kept the field up to the time of and pending the incursion of species of the early Oriskany. In this way the former became a true and proper part of this new fauna with whose indicial species it coexisted throughout the remainder of its duration. A modification so gradual as to permit such an uninterrupted existence cannot sever the close relation of the one fauna in its entirety to the other. It is therefore a natural corollary from the account given of the Oriskany fauna, to consider briefly the relation of the organic assemblage constituting the typical and normal Helderbergian to the Devonic type of organic life, and that formation in its relation to the Devonic system.

Arguments are adduced from the intrinsic characters of the fauna, from correlation, and from stratigraphy.

3. Of very different nature is Mr. White's work on the plants of the Pennsylvania Coal-measures. The stratigraphical interval which he considers is occupied by the Pottsville formation, Pottsville series, or Pottsville conglomerate. It is described as a series of largely arenaceous beds of variable thickness which in eastern Pennsylvania lies between the Maunch Chunk red shale, or distinctly Lower Carboniferous, and the lower productive Coal-measures, or distinctly Upper Carboniferous.

The investigation was intended to establish three propositions: (1) The exploitation and elaboration from, a stratigraphic standpoint, of the fossil plants of the Pottsville formation in the type region of the southern anthracite coal field; (2) the critical analysis and comparative study of the plant material collected, with a view to the discovery of the existence of any natural paleontological subdivisions, zones, or horizons, and their paleontologic characters, or the species of stratigraphic value; (3) the discovery of the paleontologic limits as differing or as agreeing with the lithologic limits of the type section, and the consequent paleontologic definition of the formation.

The main aim of the investigation is the paleontologic definition of the terrane.

Two other, largely concomitant, results that are either economic or scientific in their nature have also been reached in the process of the elaboration of the fossil plants of the formation in the typical region. The first, of some economic interest, is the correlation of the groups of beds, or of individual

coals wrought in disconnected or somewhat isolated portions of the southern anthracite field. The other, which concerns the question of general geological correlation, is the acquisition of data for the determination of the age of the Pottsville formation—*i. e.*, (*a*) the time interval represented by the type section, and (*b*) the equivalents, in a broad sense, of the formation in other basins of this province and in other parts of the world. Incidentally also, through the discovery in the Pottsville of floras already more or less completely known from isolated and uncorrelated terranes in other regions of the United States, the way is opened to the proper reference and correlation of those terranes with the Pottsville, or with portions thereof.

As introductory to the consideration of the plant remains as a means of geological classification there are presented a sketch of the general geological structure of the southern anthracite coal field, a description of the Pottsville formation in the typical locality, the composition of the formation, the coals contained, and their commercial names as guide horizons.

A type paleobotanic section of the Pottsville is then discussed, and the groupings of beds are enumerated. The various species and their observed distribution within the formation and in the field is given in detailed tabulated form, in which all the species are listed, together with their respective ranges. The floras of the several subdivisions indicated are discussed in some detail. The correlative comparison of the horizons of the southern field with those of the other anthracite fields is of special interest.

A considerable portion of the memoir is devoted to the description of the most characteristic species of plants found in the Pottsville, and to notes on many other species.

One of the most surprising, as well as interesting, facts observed in the study of the Pottsville floras is the large element that is common in the latter and to the flora described by Sir William Dawson from the supposed Middle Devonian beds of St. John, New Brunswick. In fact, taking into view the entire flora of the Pottsville formation in the Appalachian province, the identities in the composition of the floras are so great, with respect to both genera and species, as to leave little room for doubt that we have in the "Fern Ledges" at St. John beds of nearly the same age as the Pottsville formation in Pennsylvania. On the whole, while recognizing in the Pottsville formation a group of terranes equal in rank to the Lower Coal-measures, Alleghany series, etc., I do not favor a classification which relegates the entire formation hard and fast to the Upper Carboniferous, but I even anticipate a possible necessity for its permanent division into two groups, the lower

of which may eventually perhaps be referred to the Lower Carboniferous. From a paleobotanic standpoint the Pottsville formation is the beginning of Mesocarboniferous.

Briefly stated, the following are some of the general conclusions reached :

No evidence of a marked or general unconformity between the Pottsville and Mauch Chunk is noticeable in this region, though at various points within several hundred feet of the strata beds of small bowlders or coarse conglomerates are imposed, in knife-edge contact, on the distinctly uneven surfaces of olive-green mud-beds.

The flora in the roof of the Buck Mountain coal, or its supposed equivalents, at the base of the Lower Coal-measures at Pottsville is a typical Coal-measures flora, very distinct from the floras typical of the Pottsville formation.

The fossil plants of the Pottsville formation in the type region exhibit a rapid development and series of changes or modifications, which, if treated with great systematic refinement, are of high stratigraphic value. With the exception of the species from the topmost beds of the formation, the ferns are, in general, readily distinguished specifically from those at the base of the Lower Coal-measures, or Alleghany series, as recognized in the northern United States, while the floras of the lower portions of the section are found, in passing downward, to bear still less resemblance to those of the Lower Coal-measures. Two principal divisions of the formation, to which comparatively few fern species are common, are recognized. These divisions, which coincide with the natural grouping of the Lykens coals, are here termed the Lower Lykens division and the Upper Lykens division. A portion, including about two hundred feet of the type section between these two paleontologic divisions, contains a mixed flora, and has been temporarily designated the Lower Intermediate division.

Further paleontologic study of the Pottsville formation appears to fully confirm the earlier conclusion, based on the examination of the plants, that the thinner sections of the formation along the northern and western borders of the Appalachian trough do not contain beds as old as those in the lower portion of the thick sections along the eastern border, *e. g.*, in the Schuylkill and Great Flat Top regions. The positions of the respective floras in the sections plainly indicate a transgression of the sea toward the north and west during Pottsville time.

Both lithologically and paleontologically the Pottsville formation constitutes a division of the Carboniferous coördinate with the Lower Coal-measures, Alleghany series, etc. As such it forms the lower member of what may in a broad sense, be termed the Mesocarboniferous in the Appalachian province.

The lowest beds in the thickest sections, which appear to be continuous by transition with the deposition of the Maunch Chunk red shales, are perhaps to be regarded as coarse, coast-detrital redepositions, contemporaneous with the uppermost beds of the red shale or marine Lower Carboniferous sediments of other regions.

The flora of the Pottsville formation is so far identical, in both its generic and its specific composition, with that from the supposed Middle Devonian beds at St. John, as to leave no room for a great difference in the age of the latter.

CHARLES R. KEYES.

Iowa Geological Survey; SAMUEL CALVIN, State Geologist; A. G. LEONARD, Assistant State Geologist; Annual Report for 1900 (Vol. XI, 519 pages, 12 plates, 43 figures, 9 maps. Des Moines, 1901).

In scope and style this report follows closely the previous volumes of the series. It includes the usual administrative reports, the statistical reports of the mineral production, and detailed reports on Louisa, Marion, Pottawattamie, Cedar, Page, and Clay and O'Brien counties, the last two being treated together. These reports are written by J. A. Udden, B. L. Miller, J. A. Udden, W. H. Norton, Samuel Calvin, and T. H. Macbride respectively. They contain a careful review in each case of the local geology and serve to put on record facts and observations which may be used in later discussion of the theoretical problems involved. Following the usage of the survey, these discussions are taken up as fast as the development of the general survey allows them to be intelligently discussed. In the case of Louisa county, for example, the problems of the drift of that region have already been discussed in their theoretical phases in Mr. Udden's report on Muscatine county, Mr. Norton's report on Scott county, and Mr. Leverett's well-known monograph.[1] In the Louisa report Mr. Udden gives many interesting and valuable details confirmatory of the

[1] U. S. Geol. Surv., Mon. XXXVIII. The Illinois Glacial Lobe.

general conclusions already reached. In the Cedar county report, on the other hand, Mr. Norton places clearly before the reader the facts as to the structure and situation of the beautiful land forms to which McGee has given the name *paha*, and also states the various hypotheses which have been suggested for their origin. He makes no attempt, however, to balance the probabilities and reach a decision in the matter. The same method is observed in the discussion of the high dips observed in the Gower limestone of the Niagara. This is confessedly a difficult problem, and its solution is wisely left until the whole area shall have been studied.

In the reports on Page and Pottawattamie counties the survey takes up the southwestern portion of the state. Apparently most interesting results are likely to follow this survey. Mr. Calvin's suggestion that the drift of Page county may be the pre-Kansan instead of the Kansan fits in with many of the known facts of the field in Iowa and neighboring states. It is a far-reaching suggestion, and the development of the hypothesis will be watched with interest. In Pottawattamie county the facts are possibly susceptible of either interpretation. Mr. Udden does not, however, discuss the probabilities. His report is particularly interesting to the general student in the large use which he makes of mechanical analyses in the study of the drift. This is a method which seems likely to become more and more useful in the study of unconsolidated materials. The important results already reached by Whitney in the study of soils seem merely the forerunners of what is possible on a wider application of the method to the study of geological problems in general. Mr. Udden's hypothesis of the origin of the rivers of the county is ingenious, but the argument is not altogether convincing. The suggestion that the surface of a great ice sheet would afford a better opportunity for the development of such a regular system of rivers than the drift surface left by the melting away of the ice seems open to question. The surface of the Kansan drift, it is true, is everywhere notably even. It is impossible, however, to suppose that so thick and widespread a drift sheet as this would be laid down without the development of moraines and other surface irregularities. Yet such irregularities, where they now occur, are very faint, and are apparently the marks of much greater original irregularities. The present plane surface seems likely to be a result of erosion itself. Remembering the long period since these older drifts were deposited and the manifestly great erosion to which they have been subjected, it

seems a bit fanciful to believe that the streams now have a general course originally developed on the top of the ice. It is also difficult to imagine how streams, granting that they were developed on the ice in a symmetrical fashion, could be transferred to the drift surface during the melting of the ice without disturbance of their arrangement. If the disappearance be supposed to be accomplished by frontal retreat, the edge of the ice itself will give a sufficiently marked line for the development of the cross streams, and the major streams would in all probability be developed normal to the ice front. This apparently accords with the facts of the field and does not involve the difficulty of accounting for the development of a vigorous surface drainage on the ice and its transfer to the drift surface without notable destruction of its arrangement. The whole problem is an interesting one, and certainly Mr. Udden's hypothesis, if valid, is widely applicable. If we are to be able from the present stream arrangement to infer so much regarding the condition during glacial times a considerable step in advance is made. This fact warrants the closest skepticism in examining the hypothesis.

The volume as a whole is one which geologists will welcome. While the long series of annual reports made up of separate county reports is confusing to one not familiar with the region, the survey is systematically building up a work which will prove valuable not only to students of the local geology but to geologists in general. The work will lend itself to final summary treatment, and in the meantime the county reports not only serve a useful purpose locally, but enable outsiders to keep in touch with the results. The progress map of the drift mapping (plate II) is particularly valuable in this regard.

H. F. B.

Beach Structures in the Medina Sandstone. By H. L. Fairchild. American Geologist, Vol. XXVIII, pp. 9–14, plates 2–6.

In the July number of the *American Geologist* Professor H. L. Fairchild discusses the "Beach Structures in the Medina Sandstone." The features considered are certain troughs and swells of a breadth ranging from thirty to eighty feet. These are assumed to be of the same nature (probably in some cases the same examples) as those which formed the basis of Dr. Gilbert's theory of "giant ripples." Gilbert had concluded (*Bulletin Geol. Soc. Amer.*, March 1899) that with

"certain combinations of amplitude and frequency" the largest ocean waves might produce ripples having a length equal to half the height of the wave. The supposed giant ripples observed at Lockport, N. Y., reached a length of thirty feet, implying waves sixty feet high in the Medina sea. Fairchild explains the same features as spits or rather beach ridges, sometimes observed in series of as many as four crests with intervening troughs. Of the fifteen halftones with which the article is illustrated, about one third are clear enough to show without doubt that the features referred to are of the same nature as those discussed and figured in Gilbert's article. Four of the cuts show sand ridges on the present shore of Lake Ontario which are supposed to exemplify the process by which the features in the Medina were made. The remaining cuts and a few expressions in the article leave it in doubt as to whether the features observed were all of the type from which Gilbert's conclusions were drawn. The latter found no intervals of more than thirty feet from crest to crest; the article under discussion refers to similar spacings of eighty feet. Gilbert's discussion of the features as ripples implies a symmetry or at least unity in the trough by which its breadth could be fairly estimated when only a portion could be seen. Fairchild speaks of the trough as only a "negative or passive element" which may have any width varying with the accidents which determine the location of a new beach ridge. The observations of both, and both interpretations, involve abundant cross bedding. It would seem that the two processes hypothesized would produce different dispositions of this crossbedding, as well as differences in the symmetry of the trough. Gilbert shows by diagram the necessary arrangement of the crossbedding under various suppositions as to the shifting of the ripple system during deposition. It is quite improbable that the patterns in vertical cross section thus produced would be duplicated in a series of beach ridges. In the latter case the lamination on the landward side of an outer ridge should be plainly distinguishable from the lamination on the lakeward slope of the next ridge within. The lamination corresponding to this latter slope should disappear only in the most extreme cases of landward migration of the ridge, a condition quite improbable where a series of ridges is produced. Fairchild's objection that ripple marks are not found of intermediate sizes between eight inches and the "giants" is certainly of interest.

N. M. F.

The Beaufort's Dyke, off the Coast of the Mull of Galloway. By H G. KINAHAN. Proceedings of the Royal Irish Academy, Third Series, Vol. VI, No. 1.

In the Proceedings of the Royal Irish Academy, Third Series, Vol. VI, No. 1, Mr. H. G. Kinahan, District Surveyor (Retired), H. M. Geological Survey, describes "The Beaufort's Dyke, off the Coast of the Mull of Galloway." This "dyke" is a deep trough in the bed of the Irish Sea nearer the coast of Scotland. The plate accompanying the article reproduced from the Admiralty charts, shows a long line of soundings of 100 to 148 fathoms, surrounded by a comparatively level bottom 70 or 80 fathoms deep. Attention is just now directed to these depths by the proposition to construct a tunnel from Scotland to Ireland. The geological interest lies in the fact that in this trough "there are sands, gravels and their adjuncts, at depths of from 120 to 144 fathoms that are carried backward and forward similarly to those on an ordinary sea beach." This is much deeper than the waves and currents even on most exposed coasts have been supposed to act. The vigor with which this deep washing occurs may be inferred from figures given in a table, which show that at one point the bottom was cut down by erosion from a depth of 117 fathoms to a depth of 146 fathoms from 1894 to 1897 or nearly 60 feet a year. At other times filling was similarly rapid. The origin of the dyke or trough itself is left in doubt but faulting and glacial action are suggested. The origin of currents capable of acting at that depth is the main subject of interest. It is assumed that while the effect of wind waves and tide waves is reduced to zero at moderate depths there are deep currents induced by these superficial waves, to the depth of whose action no definite limit is assigned. The author contrasts these currents with the ordinary tidal races which may be supposed to erode shallow places more than deep ones. He refers to his former publications for detailed proof that denudation by these currents in question "is in ratio to the depth of the water." The whole article goes to show that when the movements of water are controlled by channels or reflected from irregular shores, the coarseness of the sediments at given depths bears little relation to the mathematically computed power of the water for those depths.

N. M. F.

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INDIVIDUALS OF STRATIGRAPHIC CLASSIFICATION.

INDIVIDUALS TO BE DISTINGUISHED.

SHOULD geologists map the record of physical conditions or the record of biological conditions — rocks or fossils? Both, but with distinction.

When the geologist enters the field to do stratigraphic work, one of the first problems to confront him is where he shall divide the series of rocks he is studying; and often, when reading a paper, we are perplexed to know where these lines have been drawn and what the divisions are intended to represent. This discussion is an effort to arrive at a better understanding of what we classify and what may be mapped.

Since the earliest days of geologic work there has been recognition of different kinds of rocks. For many years geologists compared the various rocks they found, and correlated them from continent to continent on the basis of like physical conditions represented in the similar lithologic characters of the rocks, Identity of physical conditions was interpreted as indicating the same date, but we now know that the physical characteristics of rocks are repeated from time to time, and are diverse in different provinces at the same time, and that therefore they do not afford criteria of contemporaneous deposition. Furthermore, conditions of sedimentation are related to currents, shores, and other moving features; the zones of deposition may migrate

with these features, and an identical sediment accumulate in the migrating zone successively, not simultaneously, over adjacent areas.

After the days of William Smith a second class of divisions arose — divisions based on the fossils which the rocks contain. Fossils were found to occur in certain associations, which were called faunas, and these became the basis of a classification of rocks. On the hypothesis of special creations and destructions each fauna, wherever occurring, represented a certain date, and thus faunas became the significant figures expressing age. But special creation has given way to evolution, and we recognize migration of faunas as a fact. For instance, Walcott has stated that it took a long time for the Olenellus fauna to move round the globe. A greater or less time interval must elapse between the earliest appearance of a fauna at one place and its earliest appearance at another place remote from the first, hence, a fauna does not indicate a precise date in the narrow sense in which it was once taken. Professor H. S. Williams has pointed out that in a wider sense any fauna endures a length of time, from its initial appearance somewhere to its extinction everywhere; and this interval is an episode of evolution which has a fixed place in geologic history. In that sense faunas have definite time values, but the discovery of that value in any case is dependent on refined and extensive paleontologic research.

Accordingly, when studying a stratigraphic series, a geologist may recognize distinctions of lithologic character, variations of faunal content, and succession of physical or faunal changes. The differences enable him to define lithologic individuals, faunal individuals, and time intervals. Though often intimately related, sediments and faunas are by no means necessarily bounded by the same limits in space or in time; they constitute not identical but unlike things. They may migrate together or independently. Either may cease and the other continue. When each of them has been described and discusssed in its local and general relations, the problem of correlation in terms of earth history may be hopefully attacked; but when strata and faunas are treated

under one name, confusion ensues and the conclusion becomes a guess.

It follows that we need to recognize, define, and name three separate things: (1) lithologic individuals; (2) faunal individuals; and (3) time intervals.

LITHOLOGIC INDIVIDUALS.

Definition.—Some twelve years ago there was held a conference of the geologists of the United States Geological Survey, and at that time the basis for the Geologic Atlas of the United States was laid. That foundation was planned upon the simplest lines. It was proposed that the maps should exhibit the distribution of local lithologic individuals.

Referring to the *Tenth Annual Report*, Part I, in the account of that conference we find the following statement (pp. 63–64): "Among the clastic rocks there shall be recognized two classes of divisions, viz., structural divisions and time divisions." Observe that time is set off in contrast to structure, and that structure is not defined by time. Then, defining structural units, the report says (p. 64): "The structural divisions shall be the units of cartography, and shall be designated *formations*. Their discrimination shall be based upon the local sequence of rocks, lines of separation being drawn at points in the stratigraphic column where lithologic characters change." Proceeding to emphasize that, the report further says (p. 64): "Each formation shall contain between its upper and lower limits either rock of uniform character or rock uniformly varied in character." By the latter phrase it was recognized that there might be groups of lithologic individuals which singly could not be mapped because too small—a difficulty which had to be met from the practical side. Furthermore, the report says: "As each lithologic unit is the result of conditions of deposition that were local as well as temporary, it is to be assumed that each formation is limited in horizontal extent; the formation should be recognized and should be called by the same name as far as it can be traced and identified by means of its lithologic characters, *aided by its*

stratigraphic association and its contained fossils." (Italics the present writer's.)

Formations and fossils.—That the purpose of the definition is to emphasize lithologic character, and make it the essential of individuality of a formation, is clear, but the habit of classifying roughly by fossils is strong, and the few words here italicized have led many to lose sight of the distinction intended. There is a difference between using fossils as one of several means of identification and employing them as essential characters. In the former case, other characters being the same, the occurrence of a known fossil is an aid, but its non-occurrence sets no limit. In the latter case the range of the characteristic fossils defines the extent of the division. By the one method we may define a lithologic formation according to all its characters. By the second method we limit the lithologic unit by a fauna and a fauna by the lithologic unit, when either may occur beyond the other; and thus, combining two unlike things in one definition, we can recognize neither.

The writer by no means advocates disregard of fossils in the identification of formations. But abundant experience of the ablest stratigraphers shows that classification by faunas requires most refined investigation based upon thorough knowledge of the rocks. To map the formations is a necessary preliminary to determining the faunal units. We should proceed from the simple and obvious to the complex and obscure. We should trace out lithologic individuals, according to their constitution and stratigraphic associations. If these leave us in doubt, fossils may prove valuable ear-marks; but they should not set limits in the discrimination of formations. When the map of formations is made, the way is prepared for the paleontologist to ascertain the number and bounds of the faunal units and to draw the faunal map.

In mapping formations it is convenient to combine them in systems—Cambrian, Cretaceous, Eocene, etc. Fossils are the means of this preliminary rough classification, and the little evidence required is usually obtained in studying the lithology.

But it would be a slur upon paleontology to consider such arrangement final. Even were the dividing planes between great systems fixed, the precise recognition might require detailed investigation of faunas; but in many cases they are not fixed beyond question, either by faunas or by unconformities. Geology has not arrived at a final classification. We need still to accumulate physical and biological facts, to keep them distinct, and to compare them from district to district, and from country to country, before our systems can be said to be established.

The writer is indebted to his colleague, Mr. Whitman Cross, for a case in point—that of the Hermosa, Dolores, and Rico, so-called formations. Quoting from Mr. Cross's statement before the Geological Society of Washington (as revised by him), the case is as follows:

[A diagram exhibited] represented the problems in subdivision of the great series of alternating shales, sandstones, conglomerates, limestones, and strata of intermediate lithologic character represented in the Rico quadrangle, southwestern Colorado. This series of rocks, about 4,500 feet in

Mesozoic	Dolores formation (Triassic)	Red
Paleozoic	Rico formation (Permo Carboniferous)	....
	Hermosa formation (Upper Carboniferous)	Gray

thickness, extends from the base of the Upper Carboniferous to the top of the Trias. The lower 2,000 feet of strata are characterized by Upper Carboniferous fossils. The intermediate three or four hundred feet by a well-defined Permo-Carboniferous fauna, and a considerable portion of the upper 2,000 feet by Triassic fossils.

Recognizing the importance of the time divisions indicated, the Upper Carboniferous strata have been grouped as the Hermosa formation; the strata bearing the Permo-Carboniferous fossils as the Rico formation; the strata containing Triassic fossils as the Dolores formation. With the Triassic strata are provisionally included at the present time other strata not known to be fossiliferous. The upper limit of the Dolores is a definite lithologic and structural horizon. The lower limit cannot be determined upon lithologic grounds alone. *As a line must be drawn on arbitrary grounds*, the Dolores complex has been extended below to the uppermost stratum containing

Permo-Carboniferous fauna. This alternation of strata of different lithologic character can be subdivided in great detail when the exigencies of mapping require it. *The important lines limiting the Rico formation above and below cannot be drawn upon lithologic grounds.* If lithologic character alone is relied upon for the subdivision of this great complex embracing strata belonging partly to the Paleozoic and partly to the Mesozoic, the formation units would be of relatively minor importance, and the great historical subdivisions would not be expressed. The criterion of color applied to this complex groups the Permo-Carboniferous with the Trias. This has been done in previous general discussions of this complex in this region. In fact, the Permo-Carboniferous beds should be grouped with the Carboniferous if the larger elements of time division are to receive recognition upon the geologic map of the Rico quadrangle. (Italics the present writer's.)

There are two questions involved: First, what Mr. Cross's map expresses; second, what it should express. The Hermosa, Rico, and Dolores are clearly not formations in the sense defined in the *Tenth Annual Report*, for lithologic continuity is divided at the top and bottom of the Rico on the basis of contained fossils. They are intended to be faunal divisions, but their limits are very ill defined, since fossils are commonly so few in the Red Beds that the finding of them higher or lower in the series is a matter of accidental discovery rather than of occurrence. The map appears, then, to express indefinitely the arbitrary application of a time scale (Paleozoic, Mesozoic or Carboniferous, Permo-Carboniferous, Triassic) to a series which is capable of division into lithologic individuals. Were it so divided it would yield a record of physical conditions, a record which is now obscured by this classification.

It is an important fact that conditions of erosion and deposition were continuously favorable to the accumulation of red sediments while biologic migration or evolution modified the organisms present from Paleozoic to Mesozoic types. But in discussing the formations their continuity is the essential, just as in describing the faunas their discontinuity would be. To impose the division of the latter upon the lithologic individual is misleading, and to call the faunal units "formations" in a publication for which that term has been accurately defined is a misuse of the word.

A very similar case is that of the Shenandoah limestone, which carries Cambrian fossils in its lower portion and Calciferous fossils near the top. But, though it thus corresponds to parts of two great periods, as we usually classify geologic time, it is mapped as one formation because it is a lithologic unit.

Formation names. — "The formation should be recognized and should be called by the same name as far as it can be traced and identified by means of its lithologic characters, aided by its stratigraphic association and contained fossils." Following this rule (*Tenth Annual Report*, Part I, p. 64), various cases may arise, some of which are illustrated in the accompanying diagrams.

Figure 1 shows the *m* shale passing into a limestone which retains identical stratigraphic associations. Being exactly continuous stratigraphic units, they should retain the same geographic name on grounds of convenience and simplicity.

Figure 2 shows the *m* shale grading into a limestone with prolonged overlap, so that the two rocks must be discriminated in one area. Not only are they lithologically different but they have different stratigraphic associations, and they should receive distinct geographic names: *m* shale and *n* limestone.

Figure 3 shows the *m* shale continuing as an individual with reduced thickness into new stratigraphic associations. Individuality is not dependent on thickness nor on stratigraphic association only; it is determined by continuity, and the formation may retain its name, *m* shale. But the group *pms* cannot then be called the *m* group, because *m* would have two meanings, one for a simple part, and one for a complex whole.

Figure 4 shows the *m* shale replaced by five formations, two of which, *B* and *D*, are shales like it. Individuality is here lost in multiplicity. Neither *B* nor *D* can be distinguished as representing *m*, which must, accordinly, give way where they divide into two. The complex *ABCDE* may be called the *m* group, since it has equivalent stratigraphic associations with *m*.

Figures 5 and 6 illustrate the occurrence and naming of local lenses in a formation where such divisions are not of sufficient

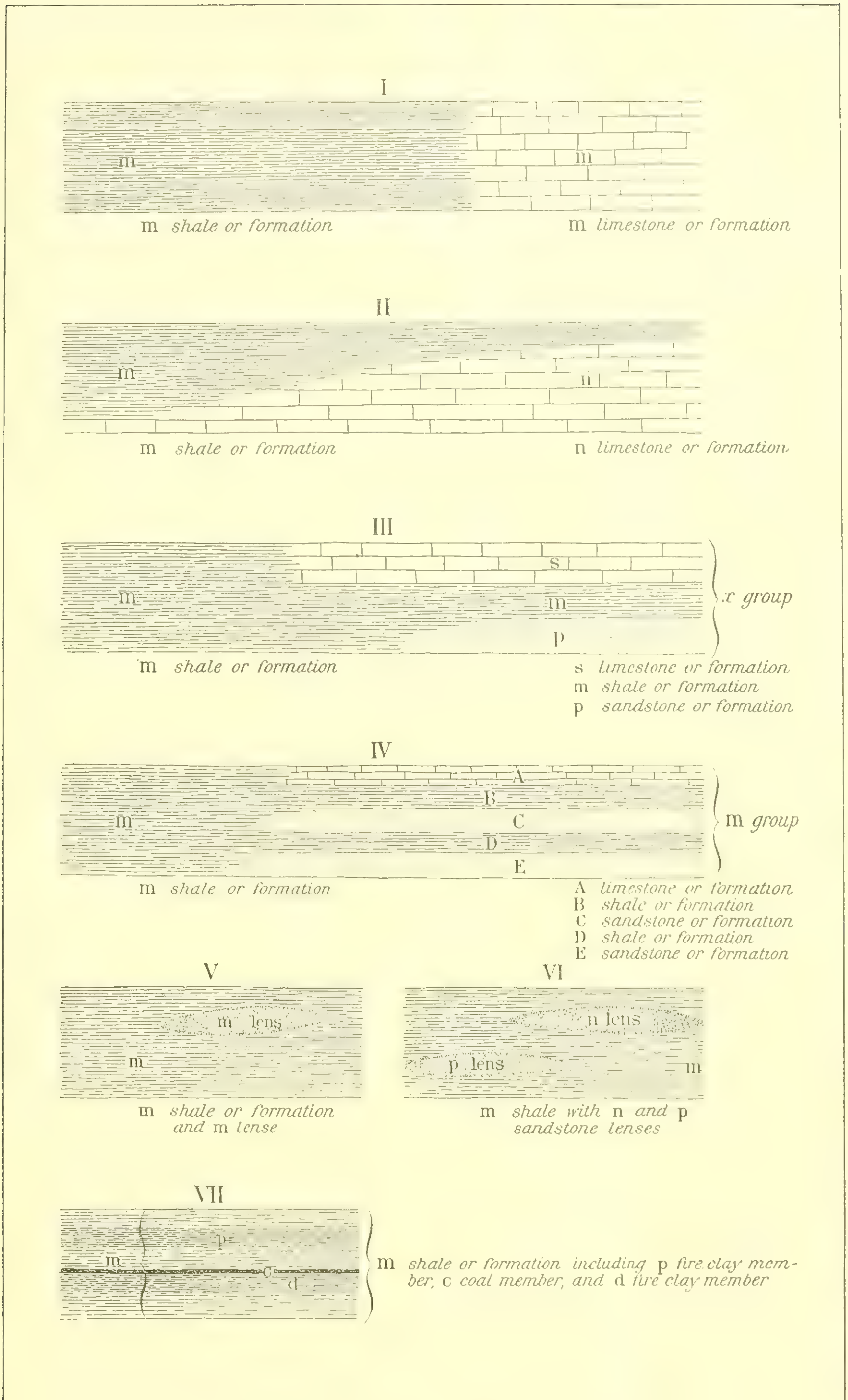
extent to justify a distinct series of names for the lens and the parts of the formation above and below it. One lens may receive the formation name, but two or more must be named distinctly.

Figure 7 presents the case of a formation which is a least practicable lithologic individual for mapping, but which includes fractional parts that are important in discussion. The fractional character of the parts may be indicated by calling them members, each member being given a distinctive geographic name.

Lithologic individual and thickness.—Thickness is not an essential character of a lithologic individual. Layers, strata, beds, and their complexes vary so generally in this respect that individuality based upon constancy thereof must be lost in a short distance. And if thickness be not constant for any one individual, still less can volume be considered an element of the definition of formations in general. Lithologic individuality knows no such limits. Continuity of rock character is the essential core of the definition, and this may extend through a hundred or a thousand feet or more or less.

The writer has avoided the use of the phrase "lithologic unit," because discussion developed the fact that, in the minds of some, unit means a definite quantity, and these persons think that a thick formation should be a group or series, because of its magnitude. Not volume, but uniformity of constitution, defines a lithologic individual or "formation."

Lithologic individual and time.—Thickness of strata, at right angles to bedding, is considered a measure of the epoch of deposition, due account being taken of the estimated rate. Thus for that particular place the lithologic unit is significant of definite lapse of time. It bears, however, no mark of date. If we trace the formation a hundred or a thousand miles, and again measure its thickness, another determination of an epoch is obtained, again without date. Are the epochs identical? The common assumption is that they are, and one reads of the epoch of the Dakota formation without reference to locality. Thus used, the phrase should mean all the time during which the Dakota sandstone was spread from its eastern to its western


I
m
m
m shale or formation
m limestone or formation
II
m
n
m shale or formation
n limestone or formation
III
s
m
m
p
x group
m shale or formation
s limestone or formation
m shale or formation
p sandstone or formation
IV
A
B
m
C
D
E
m group
m shale or formation
A limestone or formation
B shale or formation
C sandstone or formation
D shale or formation
E sandstone or formation
V
m lens
m
m shale or formation
and m lense
VI
n lens
p lens
m
m shale with n and p
sandstone lenses
VII
p
m
c
d
m shale or formation including p fire clay member, c coal member, and d fire clay member

limit. Since that transgression took a long time, the eastern Dakota sandstone is older than the western; and as the advancing zone of sand accumulation, following the shore, was in turn followed by a zone of shale deposit, the eastern sands were being buried under Benton shale while the western sands gathered. When the transgression ceased and Niobrara chalk was laid down, the conditions were more nearly uniform throughout the sea. Niobrara then probably marks approximately one and the same epoch throughout its extent. Benton may do so in less exact degree; and Dakota corresponds at an eastern point to the beginning, at a western to the closing, of the cycle of deposits.

It is convenient to conceive the time scale as marked by horizontal lines. On such a scale the Dakota formation would be represented by a diagonal line, and the Niobrara by a nearly horizontal line.

The writer does not put these ideas forward as new; but in defining a formation it is important to clear away certain misleading conceptions that appear in the literature and in discussion of the points at issue. Only at a particular place does a formation belong to a definite age: when traced to another locality it may be older or younger.

FAUNAL UNITS.

Classification by faunas.— The term faunal unit or individual is here used as a parallel to lithologic individual, to designate a set of strata characterized by a common fauna. The writer does not undertake to say whether a fauna should be defined by varieties, species, or genera; by recognition of one or many associated organisms. It may be granted that a fauna is something which each working paleontologist will define for himself within certain broad limits, just as lithologic character is something which each stratigrapher defines for himself within certain limits. But classification of strata by faunas is a different thing from classification by formations.

Professor Williams, in 1897, published a paper on dual

nomenclature, in which he clearly stated the distinction which the present writer would now emphasize between a lithologic individual and a faunal unit.

Following the language in which a formation is defined in the *Tenth Annual Report*, a faunal unit may be defined as follows:

LITHOLOGIC INDIVIDUAL.	FAUNAL UNIT.
"The structural divisions shall be units of cartography, and shall be designated *formations*. Their discrimination shall be based upon the local sequence of rocks, lines of separation being drawn at those points in the stratigraphic column where lithologic characters change."	The faunal units shall be units of correlation, and shall be designated stages.[1] Their discrimination shall be based upon their fossil content, lines of separation being determined at those points in the stratigraphic column where faunas change.

Pursuing the description of a faunal unit, or stage, we may say further: As a faunal unit is characterized by the life which it contains, and as organisms are migratory, it is not to be assumed that a stage is limited horizontally. It may be recognized in diverse provinces or continents, and therefore the name which a faunal unit receives should not be a local name, but should be applied wherever that unit is recognized.

Distinctions between formation and stage.— A formation is a set of strata characterized by and limited to uniform constitution. A stage is a set of strata containing and limited to a certain fauna.

Lithologic constitution results from conditions which are local and temporary, and which, though migratory, are rarely more than provincial in extent. A fauna, though evolved in adaptation to local conditions, may be capable of world-wide migration. A formation, therefore, is geographically limited; a fauna is not, necessarily.

Physical conditions which determine rock constitution are recurrent and repeat the deposition of similar sediments. But organisms, once extinct, do not reappear. Accordingly, a

[1] The term *stage* is here used provisionally, to afford a word for the purposes of this discussion only.

formation may belong to any geologic age; a fauna belongs only to that age in which it was evolved and died out.

A principal object in studying formations is to read the physical history of the earth, but the principal object of investigating fossils is to get at the life history. Each is an essential aid to the other, and the time relations of fossils are fundamental. But the two lines of inquiry should not be confused. They are confused when we call a stage a formation, or *vice versa*, or place the limitations of the one upon the other.

STEPS IN GEOLOGIC SCIENCE.

The question with which this article opens may now be given a fuller answer. The first step in the geologic study of any locality is to ascertain the relations of the rock masses, and those relations are most happily expressed in a map which exhibits the distribution of formations. This map illustrates local facts. It can be complete in itself, even though no connection is established between the facts of that particular district and those of the world at large, but if it be a correct map it will fit into the general record when the connections are traced.

The second step in geologic investigation is the detailed study of faunas and their distribution in stages. To this second step the first is an essential, as a good topographic map is to both. Through close analysis of the faunas and comparative study of their distribution, the data may be gathered for a map of the stages represented in the district. This map of stages may in some cases resemble closely that of the formations, but in others there will be marked differences.

With the development of maps showing the distribution of stages we may arrive at correlation of events, and thus be able to compare physical conditions the world over, fitting into its place with some degree of exactness the record of the formations for any locality. Thus correlation is the third step, a step which may be facilitated through other lines of research, but which is fundamental in broad studies of the earth's history.

With a better knowledge of the physical geography of the globe at successive epochs we may more hopefully attack the great problems of mountain growth, continental development, and earth dynamics. But our first work is to map the lithologic individuals, while our associates, the paleontologists, distinguish the faunal units of stratigraphy.

BAILEY WILLIS.

THE DISCRIMINATION OF TIME-VALUES IN GEOLOGY.

THE imperfection of the present systems of classification and correlation of sedimentary rocks concerns more directly the interpretation of the facts than the facts themselves.

The work of the geologists of the United States in mapping and recording the stratigraphic sequence of formations was never more exact and comprehensive. The paleontologist was never more particular in his records of the faunal contents of each formation and fossiliferous zone, and his comparisons were never more full and precise. But the extension of knowledge over vast territory has brought to light hundreds and thousands of outcrops of the same formations, showing a diversity of faunal composition which cannot be translated entirely into difference in geologic age.

So long as surveys were confined to local areas separated by spaces across which the continuity of formations could not be traced, it was practicable to use a system of nomenclature and classification in which lithologic formations and their stratigraphic succession were chiefly considered. When, however, the intervals between local areas were filled up and it was necessary to correlate geological sections in which the formational divisions are in part or wholly dissimilar, the duality of the lithologic and biologic facts become apparent. These two sets of facts are entirely different in nature and in origin, and for their scientific discrimination duality of nomenclature is essential.

The confusion of these two kinds of evidence was natural, and has been perpetuated by the common practice of adopting the lithologic formation as the unit of classification, making the time divisions to apply strictly to the formations instead of to the faunas and floras, by which alone the chronologic epochs in which they were formed can be discriminated. This confusion

it seen in the discussion of classification and nomenclature in the *Tenth Annual Report* of the United States Geological Survey, and in the legends of the folio maps. For instance, take the Sewanee Folio, Tennessee: The legend is as follows, viz.:

Walden sandstone - -	Carboniferous.
Lookout sandstone - -	
Bangor limestone - -	
Fort Payne chert - -	
Chattanooga black shale	Devonian.
Rockwood formation -	Silurian.
Chickamauga limestone	
Knox dolomite - - -	

According to the rules in the *Tenth Annual Report*, the first series of names are "*structural divisions* . . . . units of cartography, and shall be designated *formations*" (p. 64).

The second series of names are "*time divisions* . . . . defined primarily by paleontology and secondarily by structure, and they shall be called *periods*" (p. 65).

Although everybody understands what is meant by the classification in the legend, the principle described in the rules is wrong in that the legend on the map refers to a classification of rocks: and the real fact in the case is that in the Sewanee quadrangle the Walden, Lookout, Bangor and Fort Payne formations together constitute the Carboniferous *system*, and the map makes no record of periods of time but only of formations of rocks. The Devonian system of that quadrangle consists of the one Chattanooga formation; and the Rockwood, Chickamauga, and Knox formations are the only representatives of the Silurian system recognized on the sheet.

The European nomenclature avoids this confusion by recognizing a set of stratigraphic names and their categories; with a corresponding set of categories for the chronologic classification—the names of the divisions being the same in both the stratigraphic and chronologic scales. Instead of referring all stratigraphic divisions to one category (the formation), different

categories are used for formations of different relative size; making the list of names to be group, system, series, stage, as adopted by the international Congress. Each of these stratigraphic divisions has its corresponding chronologic category, viz., era, period, epoch, age. The European has no difficulty in expressing on the map, or in discussing, either the time or the structural relations of the formation. On the map, the Walden, Lookout, Bangor, and Fort Payne would be to him four series, together constituting the Carboniferous system. By placing the Chattanooga in the category of series he at once would indicate that he does not regard the formation as necessarily representing the whole Devonian system. On the other hand, when he speaks of the Carboniferous period he is not discussing any local set of formations but the total period of time in which lived a definite set of plants and animals, only a few of which are discovered in any one local formation. There can be no question that the systems of the European geology can be recognized in this country *only* by the fossils—but that does not change them from formational aggregates into time divisions.

The implication in the *Tenth Annual Report* that the divisions which are discriminated by fossils must be chronologic, and not structural, suggests the way in which our usage may be improved; but the fallacy of the principle is seen by noticing that the smaller formations (the series and ètages of the international nomenclature), are to be discriminated by their fossil contents as well as the larger ones (the systems). If discrimination "primarily by fossils" were to be the test as to whether the division were structural or chronologic then formations would become chronologic divisions in every newly surveyed area in which actual lithologic continuity could not be traced to some standard outcrop.

These two sets of facts (structural and paleontological) both have to do with the classification of formations on a time basis; and those who are accustomed to frame their conceptions of geological time on the basis of one set of facts, find difficulty in even conceiving that there is any other basis.

TIME VALUES OF FORMATIONS.

The regular sequence of stratified sediments forms a natural geological column, which, in any particular section of the earth's crust, is so conspicuously subdivided by lithologic differences in kind of sediments that the divisions form the most satisfactory kind of natural time division for geological classification.

These natural, lithologic divisions of the crust of the earth are technically called formations in the nomenclature of the United States Geological Survey. And in any standard section, such as that of New York state, the order, composition and thickness of the several formations is exactly known; and for that section, too, the fossils of each separate formation are known accurately and in large numbers. Geologists have been accustomed to use such a local column of known geological formations as a *standard time scale;* and as examination has extended to sections of the crust in other parts of the continent, the classification and correlation of the other columns have been made to correspond, by correlation, with such a standard column of formations. Two methods have been used in establishing the correlation: (1) by tracing continuity in the lithologic formation; and (2) by recognition of identity of the fossil species contained in the formations. Both of these methods have rested on an assumed interpretation of the facts, the correctness of which may be questioned quite independently of the established fact of continuity or of identity.

The assumptions on which these interpretations rest are that correlations of time relations can be established in the first case by *continuity of lithologic formation*, and in the second case by *identity of fossils*. In regard to the first case, it would be incorrect to say that the assumption is entirely false, for in some cases, and to a limited extent, lithologic continuity of a formation is undoubtedly synonymous with sameness of the period of the sedimentation represented by the formation. But the facts are abundant, and well known to all field geologists, to prove that formational continuity is not co-ordinate with lithologic uniformity; and since our standard definition of a formation

(*Tenth Annual Report*, United States Geological Survey) is based upon its lithologic uniformity, it is certain that in all cases in which the lithologic changes affect the upper or lower limits of a formation (which is expressed by thinning or thickening of the formation) there must be discordance between the formational continuity and the time represented by it. It requires but a moment's reflection, further, to show that two sections in different regions may, on other evidence, be known to represent the same interval of time but present no similarity lithologically; this can receive only the one interpretation that formational discontinuity does represent time uniformity, which is the converse of the original assumption.

In other words, while it is practicable in some cases to assume that formations which are clearly continuous may be deposited during the same period of time, it is clear that lithologic uniformity (by which the continuity of the formation is recognized) is not a safe guide in making chronologic correlations, however much value may be placed upon the lithologic divisions of a standard geologic section, as natural divisions of a geologic column made on a time basis. The tracing of time equivalences by formational continuity is unsatisfactory, not because of any failure on the part of a formation, as a lithologic unit, to represent a definite period of geologic time, but because the time relations of the formation are not expressed by any of the lithologic characters by which one formation is distinguished from another. The confusion the geologist is apt to fall into in discussing this point may be illustrated by the measurement of the altitude of a rock outcropping on a mountain side. The base of the Olean conglomerate, for instance, as it appears at Olean Rock City may represent exactly the altitude of 2,340 feet above the level of the sea (*McKean County Report, Second Pennsylvania Geological Survey*, R. 59), but its altitude above the sea has no relationship whatever to any of its lithological peculiarities. In forming an altitude scale, it is in the region a conspicuous mark for the altitude at which it lies, and if its dip be considered, the continuity of the

conglomerate may be relied upon for estimates of approximate altitude. Nevertheless, in itself the formation possesses no altitude value, it is only a conspicuous stratum in the region where it appears, that now lies at a definite elevation above the sea — the amount of the elevation must be determined by other means. It may indicate an altitude already determined, but it has no intrinsic altitude value, and is not a measure of altitude.

In similar manner we may say that the geologic formation, as a lithologic unit, was formed at some definite epoch of geologic time which may be approximately measured by other means; but the amount of time from any datum point to the time when it was formed is not in any degree indicated by the lithologic or structural characters of the formations; and in this sense a formation may be strictly said to possess no intrinsic time value, but to require the "paleontologic evidence" to prove to what "period" of time it belongs. This conclusion might almost be drawn from the statements regarding periods in the *Tenth Annual Report* (p. 65).

It is, however, not necessary to remind geologists that fossils possess a value as means of determining the time relations of formations. But this time value of fossils will be better appreciated if attention be given to the nature of the evidence furnished by fossils regarding the period of time in which they lived.

TIME VALUE OF FOSSILS.

Fossils derive their time-value from the fact that the morphologic characters presented by them are temporary in nature. The form of a trilobite, expressed in its various morphologic characters, was constructed by organisms at a definite period of time in the history of the earth; so that the presence of a fossil trilobite imbedded in a rock formation is direct evidence of the geologic age in which alone the trilobite lived. Hence it is that for the whole surface of the earth fossils become marks of the time divisions and the means of correlating formations on a time-basis; this is the second method of correlation referred to above. Identity of fossils is direct evidence of sameness of time. But

in applying such a statement much confusion and imperfect correlation has arisen by failure to recognize *wherein consists* the time-value of the fossil.

Identity of fossils may be wrongly interpreted — a trilobite is a trilobite, it is true, but one trilobite is a *Paradoxides* and another is *Phacops;* and the one indicates an early period of Paleozoic time, while the latter indicates a much later period. Then, again, *Phacops cristata* appeared in the early part of the life history of the genus *Phacops*, while *Phacops rana* is a later species of the same genus. Thus it is evident that in speaking of *identity* of fossils one may have in mind the same *class*, the same *order*, or the same *family*, *genus*, or *species;* and the time value will differ according to the category of zoölogical classification to which the identity applies. The time represented by the morphological character of the genus *Paradoxides* is much shorter in length than that represented by the sub-class Trilobita; and the period of time represented by the characters of the genus *Paradoxides* is diverse from that represented by the genus *Phacops*. So in regard to all kinds of organisms represented by fossils: the morphological characters expressive of the more comprehensive zoölogical divisions are of greater antiquity than those of less comprehensive divisions. The time-value of a class character is, in most cases, as long as all the recorded time of stratified rocks; while the time-value of a species is often not over a tenth of that length.

In order to discuss these time relations it becomes necessary to make scientific discrimination of the characters of organisms in their time relations. First of all, what is it about the organism which is directly co-ordinate with time? An answer to this question will be reached by considering the fundamental characteristic of organisms — their *growth*. The form possessed by any organism living is expressed only as the individual grows or develops from an embryonic or *formless* state. The form is *acquired* by each individual organism; always by individual development requiring duration of time. This time is the living period of the individual. If every individual developed some

morphologic peculiarity by which it could be distinguished, each such individual would represent a definite point of time, and the succession of individuals thus distinguished would express the history of the world in terms of the life periods of the successive individuals. Practically it is impossible so to distinguish the characters of individuals that they can serve as time indicators.

The naturalist does, however, recognize characters of sufficient distinctness to differentiate one species from another. Specific characters, like individual characters, have been acquired gradually as generation has succeeded generation in ordinary reproduction. The process of acquiring specific characters is called evolution; and specific evolution takes longer time than individual development. The length of time during which in any particular race generation continues without appreciable disturbance of the specific characters of the offspring, varies in different lines of descent, and specific characters are more readily distinguished in one case than in another. But in all cases the continuity of the specific characters without special change represents a considerable period of geological time, and this length of time is measured by the presence in the formations of the same species of fossils. The period of the continuance of the same species is therefore a definite length of time for each species, since each species began at some definite time, and (unless now living) became extinct at a later definite point of time. This definiteness of the life-period of a species is independent of our present knowledge either of its measure in years, or of the thickness or stratigraphic position of the formation in which the fossils are preserved.

Having noted that the morphologic characters of organisms are temporary in nature, we may further observe that this temporary quality has to do with the vitality of the organism in a measurable way. As in the case of two living organisms we consider the vigor of that one to be the greater, which, under similar circumstances, lives the longer; so, in general, the length of endurance of a species may be taken as the measure of some

kind of enduring power which inheres in the race itself. This enduring power of organisms, expressed by the repetition of like characters in successive fossil forms, is the time quality which has already been used by geologists in making correlation of formations by fossils, and to which we must look for the making of a scientific time-scale.

In order to isolate this time quality I have proposed to speak of it as the *bionic* quality or value of the organism. *The bionic quality of an organism may, then, be defined as its quality of continuing, and repeating in successive generations, the same morphologic characters.* In the case of the unit individual, it is the *continuing* of the characters, since biologically the use of parts wastes them; and only as they are renovated may they be said to continue; the active organs are here alone under consideration, for the inactive hard parts are biologically dead parts whose endurance is dependent only on absence of agencies of destruction. If, now, we can discover some way of observing, recording, and measuring the bionic values of fossils, we will be furnished with a means of constructing a geological time-scale on a separate (not to say independent) basis from the supposed time-scale represented by the geologic column of successive formations.

In the development of such a time-scale the first point to notice is that *the characters of organisms differ in their bionic value in direct proportion to their taxonomic rank.* Thus, as we have seen in the case of the Trilobites, the characters which have ordinal or sub-class rank have persisted in the history of organisms vastly longer than the characters of generic value; and these are of greater bionic value than specific characters.

In discriminating periods in geological time we may look first to the well-known categories of zoölogy and botany, as a basis of determination of the order of rank in the time divisions, viz., the time of endurance of a specific character (or, concretely, the length of time represented by the presence of the same species in successive strata of the rocks) is of subordinate rank to the time of endurance of a generic character. And if we should adopt the name *chron* to apply to geological time-units in general,

and *biochron* to the units whose measure is the endurance of organic characters, we have a means of constructing a system of nomenclature which will express what is now known of geological time relations, and (more important still), which will serve as an aid in accumulating the necessary statistics to perfect the geological time-scale.

ORDER OF MAGNITUDE OF BIONIC UNITS.

In expanding this system of nomenclature the following table will indicate the principle upon which the fundamental units of time value will be discriminated and named. The time unit of lowest rank will be based upon the life endurance of an individual organism; the amount of organic vigor expressed by the preservation of the individual life constitutes a bionic unit of simplest or lowest rank; the individual, therefore, is an organic unit of monobionic rank. How many individual lives are possible in the life-history of a species we at present do not know, but we do know that the bionic value of the species (or, strictly speaking, of specific characters) is of an entirely higher order than that of the individual. To be more concrete the individual, the species, the genus, etc., constitute organic units of consecutively higher and higher order of bionic magnitude, which statement may be tabulated in the following way:

THE BIONIC VALUES OF THE SEVERAL CATEGORIES OF CLASSIFICATION OF ORGANISMS.

Individual - -	a monobionic unit.
Species - -	a diobionic unit.
Genus - -	a tribionic unit.
Family - -	a tetrabionic unit,
Order - -	a pentabionic unit.
Class - -	a sexbionic unit.

In the table the bionic order of magnitude is expressed by the prefix *mono-*, *di-*, *tri-*, etc.; thus the dibionic unit is an abstract mode of naming the order of magnitude of the organic force expressed in preserving, by generation, the specific characters of an organism. Comparing this with the force which preserves in like manner generic characters, the former is seen to be of second

order of magnitude, while the latter is of tertiary order of magnitude. So far the magnitudes are relative, and they become concrete only when the bionic value of the characters of some particular species or genus is considered.

Paleontologists are familiar with the very long range of the species *Atrypa reticularis*; *Rhynchonella cuboides*, on the other hand, has a very short range. In the nomenclature proposed (so long as both are considered to be species), the fact would be expressed by saying that the *Atrypa reticularis* biochron is longer than the *Rhynchonella cuboides* biochron. Nevertheless, in the familiar categories used by the zoölogist and botanist is found a means of expressing definiteness in, at least, the order of magnitude of biochrons; whereas there is no way of distinguishing the order of magnitude of geochrons, except in feet thickness. In the case of the biochron it is only necessary to indicate the name of the species or genus in order to fix a definite value to the biochron. Such values are already definitely expressed when we speak of the "reptilian age," the "age of fishes," the "olenellus zone." The definiteness is indicated by the name of the particular group of organisms made use of, or adopted as the measure of the biochron.

THE DUAL NOMENCLATURE.

In proposing a dual nomenclature it is essential to indicate this basis of measurement of the chron, and to distinguish the *geochron* (expressed in terms of feet thickness of stratified sediments of uniform lithologic constitution) from the *biochron* (expressed in terms of presence in the sediments of fossils of the same species, genus, or family).

Thus the time value of the Hamilton formation would be spoken of as the *Hamilton geochron;* while the time value of the species *Tropidoleptus carinatus* would be the *Tropidoleptus biochron.* The same kind of difference in values is observed to pertain to both biochrons and geochrons. As it is impossible to fix any standard length for the endurance of a species, so it is impossible to fix any standard of thickness for geological formations; they may vary from a few inches to many hundreds of feet in thickness.

Since the thickness, as well as the kind of sediment, varies with the geographical locality, the association of a geographical name with the lithologic character of the formation becomes a definite and precise mode of identifying a formation; so that the name "Medina sandstone" becomes a definite formation name, the characteristics of which may be observed, and their definition fully elaborated at Medina, where the formation appears with its typical characters. Its place in a geological column, its thickness, and its composition, are all made definite by the name *Medina;* any sandstone outcropping elsewhere can be classed as "Medina sandstone" only by possessing the characters considered to be essential to formational continuity and integrity. Of course one of those characters may be theoretically defined as the geologic time of its deposition; this may be indicated by the contained fossils. But formational continuity and identity may be established in the case of non-identity of fossils, and in one section the fossils may rise to a higher stratigraphic plane than in another; so that actual *formational continuity may disagree with the evidence of duration presented by the fossil species.* This fact is illustrated in the case of the Catskill formation, which is known to occupy a stratigraphic position in eastern New York and Pennsylvania continuous with rocks further west, possessing both different lithologic characters and containing fossils regarded as characteristic of the Chemung formation. Such facts find easy expression when the nomenclature is furnished us by which to separate a geochron from a biochron. The *Spirifer disjunctus* biochron is a different thing from the Chemung geochron. In defining the Chemung formation it has become necessary to distinguish it from the formation following it. This following formation in many sections in New York and Pennsylvania is a red sandstone and shale lacking the marine fossils, sometimes holding fish of possibly marine, but probably brackish-water habitat. For purposes of mapping and classifica-cation, the Chemung formation is succeeded by the Catskill formation; but the evidence is conclusive that the time of deposition of the red sediments of the Catskill formation of eastern

New York was in large measure synchronous with the sedimentation of gray rocks with abundant marine fossils, including *Spirifer disjunctus*, in western New York and Pennsylvania.

If the endurance of the *Spirifer disjunctus* fauna be made the mark of the *Spirifer disjunctus* biochron, it becomes quite possible to state and discuss the facts as they are, and to understand the natural explanation of the facts as a gradual transgression of the shore from which the red sediments were deposited westward with the progress of time. The geochron of red beds began earlier in the scale of biochrons, and as we expand the idea we will discover that it is also earlier in actual geological time, and that the biochron is the measure upon which we must depend in constructing the standard geological time-scale.

THE CONSTRUCTION OF A BIONIC TIME SCALE.

The next question arises, how shall this time-scale be constructed? First, it must be constructed, primarily, on the basis of the bionic values of the fossils. Secondly, the names of the time divisions must be distinct from those used in designating the formational divisions of the rocks. Thirdly, biological names should be chosen for the divisions, and so far as practicable, some abundant or characteristic fossil should furnish the name; as in naming formations the locality in which the formation appears in full force and with full characteristics is used. Fourthly, it cannot be expected that the divisions of an accurate time-scale, based upon many different sources of measurement of the time intervals, will present a continuous series without breaks and without overlapping of the divisions. If a single means of measuring the lapse of time were used, such breaks and lapping might be avoided; only in case the beginning of one species or fauna was everywhere dependent upon the cessation of the preceding one, could the scale be made without liability of failure to meet at the limits of the time intervals indicated. Fifthly, the classification and definition of geological formations should be made, so far as practicable, independent of the fossils or the time relations indicated by

them; and the fossils should be used (as now their use is scientifically most valuable) in establishing correlations, not in furnishing definitions. Sixthly, the selection of the grander time divisions should be made to conform, so far as found practicable, with the standard divisions of the formation scale; but their discrimination should be based strictly upon fossil evidence and not upon the lithologic or stratigraphic characters of formations. Seventhly, in forming the time-scale the continuance of the fauna in its integrity, as marked by the dominance of its characteristic species, will constitute a more satisfactory basis of discrimination than the species alone. Slight differences in the aggregate of species found in the successive strata of rocks is quite consistent with the continuance of the fauna in its integrity, and to distinguish the *fauna* as a whole from its local and temporary expression the latter may appropriately be called a *faunule*.

In constructing a time-scale on the basis of the bionic values of fossils, it is practicable to give to the categories now in use greater precision and scientific definition. If geologists chose to adopt the following terms in the restricted sense designated, such a set of terms would prove of great value.

TERMS OF THE BIONIC TIME SCALE.

Chron.—An indefinite division of geological time.

Geochron.—The time equivalent of a formation.

Biochron.—The time equivalent of a fauna or flora.

Hemera.—The technical name for a monobiochron, indicated by the preservation of the individual characteristics of all the species of a local faunule, as shown by the association in the rocks of the same species, in the same relative abundance, size, and vigor. An example is the hemera of *Rhynchonella* (*Hypothyris*) *cuboides*.

Epoch.—The name of a dibiochron, indicating the time equivalent of the endurance of a particular species and of the integrity of the fauna of which it is the dominant characteristic. An example is the *Tropidoleptus carinatus* epoch, which corresponds closely to the limits of the Hamilton formation of eastern New York.

Period.—May be defined as a tribiochron. This is the time equivalent of the continuance of a *genus*. An example is the *Paradoxides period*, which corresponds to the Acadian formation of the Cambrian system.

Era.—May be used to indicate a tetrabiochron; and *Olenide era* would indicate the life range of the family *Olenidae*, corresponding in length, approximately, to the geochron of the Cambrian system, though not strictly so.

Eon.—May stand as the name for a pentabiochron; an example of which is the *Trilobite eon*, the time equivalent of the continuance of the order, or sub-class, *Trilobita*, which closely approximates the length of the Paleozoic geochron.

CLASSIFICATION AND NOMENCLATURE OF THE TRILOBITE EON (PALEOZOIC) CONSTRUCTED ON THE BASIS OF THE BIONIC VALUES OF FOSSILS.

Eon	Periods	Epochs	Formational Equivalents (Approximate)
Trilobiteon	7. Phillipsian	Cameratus	Coal measures.
		Increbescens	Kaskaskia, St. Louis.
		Logani	Keokuk, Burlington.
		Marionensis	Kinderhook.
	6. Phacopsian	Disjunctus	Chemung.
		Mucronatus	Hamilton.
		Acuminatus	Corniferous.
		Arenosus	Oriskany.
		Macropleurus	Lower Helderberg.
	5. Calymenean	Vanuxemi	Waterlime, etc.
		Radiatus	Niagara, etc.
	4. Asaphian	?	Ordovician.
	3. Olenian	?	Cambrian.
	2. Paradoxidean		
	1. Olenellian		

Applying the principles set forth in this paper, a tentative table may be constructed which will express concretely what is meant by a biochronic classification and nomenclature. In this table the attempt is made to find names of genera of Trilobites for the periods of that eon in which Trilobites constitute a characteristic feature. The genera chosen actually do lap over each other in several places, but it is doubtful if any genera could be chosen which, if they did not lap over in their chronologic range, would leave actual gaps not represented in any division of the scale. The genus *Spirifer* is selected in the upper

divisions of the scale, as furnishing a convenient set of diagnostic species; they, too, do not in every case avoid lapping, a difficulty which it has already been said is unavoidable when the means of measurement are multiple and not mutually exclusive. The foregoing table is offered, then, as a means of illustrating the proposed plan.

HENRY SHALER WILLIAMS.

NEW HAVEN, CONN.

VARIATIONS OF TEXTURE IN CERTAIN TERTIARY IGNEOUS ROCKS OF THE GREAT BASIN.[1]

INTRODUCTION.

DURING the field work of the writer in the Great Basin, in 1899, he found in a number of localities, chiefly near the edge of the Sierras, cases of what seemed at first extraordinary transitions or intimate alternations of texture in the Tertiary igneous rocks, which are for the most part extrusive. Microscopic and comparative examination in the office corroborated the field conclusions and showed also that the transitions were not as abrupt as they seemed at first, but were more gradual; and the study of the conditions of crystallization which may be inferred from the structure of the different varieties shows that similar conditions must exist in many other places and similar transitions may be looked for. It is true that there are in that portion of the Great Basin especially under consideration (namely, the district lying within fifty miles of Carson) exceptionally favorable circumstances for the exposure of both the surface portions and the originally deeply buried portions of lavas. The region is an arid one, and therefore the general erosion is slight; nevertheless, waters derived from the moister Sierras reach out into this region in the form of streams, and have accomplished much special or basal[2] erosion. There are also a number of lakes, which in former times were much more extensive, and probably existed in one stage or another since early Tertiary times; and the basal erosion of these lakes has probably been considerable.

Some of the special localities where the observations were made will now be described in detail.

[1] Published by permission of the director of the United States Geological Survey.

[2] *I. e.*, Erosion which works at the base of topographic features, undercutting them.

ANDESITIC ROCKS.

MASON'S BUTTE.

Field description.—Mason's Butte lies close to Walker River, in Mason Valley, about four miles due south from Wabuska. It is thus situated midway between the northern end of the Walker River range and the northern end of the Smith Valley and Pinenut ranges. The rocks of the butte are related to those of all these ranges, as will be shown later. The butte itself is about a mile and a half long in a northeasterly direction, and about half a mile wide. It presents from a little distance the appearance of typical volcanic rock, being distinctly thinly bedded, with red and gray zones. On the western face of the butte is a scarp two or three hundred feet high, and from here easterly there are a series of saw teeth, caused by the unequal erosion of the bands of which it is composed; then the butte sinks gradually into the plain again. The bands of igneous rock dip easterly 15° at the western end of the butte, and the dip increases to the east, so that on the eastern end they dip 30°. Here they are locally reversed and dip west, probably from movement subsequent to the eruption, which movement is also evidenced by shearing. The beds strike parallel with the longest extension of the butte (see Fig. 1).

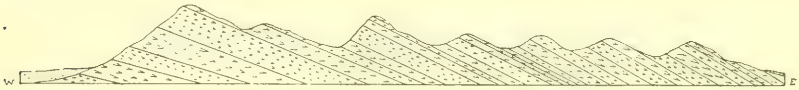


FIG. 1.—Cross section of Mason Butte, showing alternations of course and fine textured dioritic beds. Drawn to scale. Scale, 1 inch=850 feet.

Upon examination, the rocks are found to be diorite and andesite in alternating conformable layers. Fourteen different layers of diorite were found in the half-mile section, with layers of diorite porphyry and andesite between. From a structural point of view, all these rocks grade into one another. Sometimes the gradation may be actually seen in a single bed; for example, a highly porphyritic andesite, which in the field was

taken for a diorite porphyry, was found to change gradually into a coarsely crystalline diorite; but generally the beds are separate. The coarse-grained rock contains some dark inclusions, which appear to be like the finer-grained rocks. The diorite is also associated with alaskite[1] which occurs in many large segregated masses irregularly distributed, and with a few quartz veins, also segregational. The alaskite and quartz veins are found only in the diorite; never in the fine-grained rocks. At the eastern end of the butte, also associated with the diorite, are considerable masses of hornblendite which grade into normal diorite.

Although a careful search was made, no intrusive phenomena showing that the andesites are intrusive into the interbedded diorites, or vice versa, were found. Although the whole butte is of rugged rock and entirely free from any vegetation sufficient to obscure exposures, yet the succession of the different beds is as normal and regular as in the case of sediments. The andesites are evidently similar to the Tertiary andesites which occur plentifully in the whole region round about. The conclusion reached in the field, therefore, was that Mason's Butte represents the roots of old volcanic flows, that the apparent bedding is a flow structure on a large scale, and that the coarse-grained and fine-grained rocks, the diorites and andesites, are different forms of crystallization from a single magma. Some of the fine-grained rocks are separate layers from the coarse-grained ones, while some are simply variations in them. The diorite naturally incloses portions of an earlier formed crust, which is identical with the finer-grained beds.

Microscopic evidence.—The structure and composition of typical specimens from this butte will now be described:

Hornblende-biotite-quartz-diorite[2] (117 N.).—This rock in the hand specimen is medium coarse granular and rather dark, on

[1] See *Am. Geol.*, April, 1900, p. 230. *Alaskite* is proposed as a general name for rocks consisting of quartz and alkali feldspars without essential ferromagnesian constituents.

[2] These numbers refer to the specimens in the writer's collection, and are given for the purposes of subsequent identification.

account of a liberal percentage of ferromagnesian minerals. It has the appearance of a typical granular rock. Under the microscope the structure is coarse. The largest grains are as much as 8^{mm} in diameter, and these grains, which have hypidiomorphic or idiomorphic outlines, are closely intergrown. Filling the spaces left by the intergrowth of these larger grains is a somewhat scanty mesostasis, composed of grains averaging about 1^{mm} in diameter. The minerals of the larger and the smaller grains are the same, consisting of feldspar, which is greatly in excess, and quartz, green hornblende, and biotite. The quartz is distinctly subordinate in amount to the feldspar. The feldspars were tested by the Fouqué method and gave, on sections perpendicular to both the positive and the negative bisectrices, the extinction angles for oligoclase.

Hornblende-biotite-quartz-diorite (123 N.).—This does not differ in the hand specimen to any noticeable extent from 117 N. Under the microscope also the two are essentially alike, but with a slight difference. In 123 N. the larger crystals are more abundant, so that the structure at first sight appears to be coarse allotriomorphic granular. On closer analysis the section is seen to be made up of more or less idiomorphic crystals of feldspar, green hornblende, and biotite, closely packed together, with the spaces between filled with a scanty mesostasis of quartz, feldspar, hornblende, and biotite, these grains being of all sizes, commencing with the size of the idiomorphic grains just described. In this section, as in 117 N., the quartz is a subordinate essential. The feldspar, tested twice by the Fouqué method, gives the angles for andesine-oligoclase.

Hornblende-andesite (116 N.).—This is a porphyritic rock with an abundant, greenish groundmass, and is entirely similar in appearance to the hornblende-andesites of the Pinenut range, just west of the butte. Under the microscope the groundmass is found to be holocrystalline and micro granular, consisting chiefly of allotriomorphic feldspar and hornblende. The phenocrysts reach a diameter of about 2.75^{mm}, and consist of feldspar and green hornblende. The feldspars, when tested, gave twice

the extinction angles of andesine. In this section the phenocrysts are less in amount than the groundmass.

Hornblende-andesite (118 N.).—In the hand specimen this has the appearance of a diorite closely verging upon diorite porphyry. Under the microscope, however, there is found to be, between the closely packed phenocrysts, a micro-granular groundmass, slightly finer grained than that of 116 N. It consists chiefly of feldspar with some hornblende. The phenocrysts also are chiefly feldspar, with subordinate hornblende, which is largely altered to epidote. Determinations of the feldspar show that it is oligoclase. The larger phenocrysts have an average diameter of about 2^{mm}.

Hornblende-quartz-andesite (121 N.).—This rock is similar in appearance to 118 N. It has also a fine holocrystalline granular groundmass, showing no fluxional arrangement and composed of feldspar and quartz. The phenocrysts have a maximum diameter of about 3^{mm}, and consist of feldspar, green hornblende, and subordinate quartz, the last named in large rounded or corroded crystals. The hornblende is largely altered to epidote. The feldspar, tested twice by the Fouqué method, shows the extinction angles of andesine and andesine-oligoclase.

Hornblende-quartz-andesite (120 N.).—This rock in the hand specimen is dense, greenish and fine grained, having a trap-like appearance, with small phenocrysts in an aphanitic groundmass. Under the microscope the rock is seen to be much like those just described. The groundmass is fine holocrystalline, consisting of lath-shaped feldspars and hornblende, with subordinate quartz and some pyrite and siderite. There is a slight fluxional arrangement. The phenocrysts belong to a distinct generation from the groundmass (*i. e.*, there are no transitions) and consist of feldspar, pale green hornblende, and a single large grain of corroded quartz. The phenocrysts reach a diameter of 2^{mm}. The hornblende is largely altered to calcite, chlorite, and epidote.

Hornblende-andesite (119 N.).—This is from the same bed as 120 N., and is simply a variation from it. In appearance it is

somewhat different, on account of the more abundant conspicuous feldspar phenocrysts, which are, however, very small, so that the rock resembles a miniature of 121 N., reduced three or four times. Under the microscope the groundmass is seen to have been originally glassy, but now is devitrified, and has a cryptocrystalline structure, The phenocrysts attain a diameter of about 1^{mm}, and consist of feldspar and hornblende. The feldspar, upon optical examination, proves to be oligoclase. The hornblende is mostly altered to calcite and chlorite.

Alaskite (114 N.).—This in the hand specimen is a typical, rather fine-grained, dense rock. Under the microscope the structure is hypidiomorphic granular. The grains average 1^{mm} in diameter, and consist of quartz, orthoclase, and microcline in somewhat equal proportions. The only dark minerals present are a few grains of chlorite and pyrite.

Hornblendite (124 N.).—This is a coarse-grained rock, typical of its kind, and also consists of green hornblende, with blotches of epidote. Under the microscope the structure is seen to be allotriomorphic. No other minerals are present save those mentioned, and the epidote is secondary to the hornblende. In the section studied the grains average about 3^{mm} in diameter.

Analysis of structure.—The series of rocks just described, from 117 N. to 119 N., inclusive, shows a transition, which has at one end a typical coarse granular rock and at the other a porphyritic rock with a glassy groundmass. In the intermediate stages the phenocrysts increase in numbers and somewhat in size, while the groundmass shrinks in volume and becomes also coarser. In 123 N., which is a typical granular rock only slightly removed from 117 N., these phenocrysts have increased until they nearly fill the rock, while the small portion of groundmass which remains has coarsened so that the grains are a millimeter in diameter; thus the rock at first sight appears a typical allotriomorphic granular rock, from which it is moreover not far removed.

The very slight variations of structure between any two adjacent members of this transition series shows that the differences

in condition which brought about the separation of the coarse-grained from the fine-grained rocks were relatively small. These differences are plainly longer cooling periods (and hence longer crystallization intervals) in some portions of the rock, as compared with others. The coarse granular rocks, judging from their almost complete and uniform crystallization, have crystallized entirely in their present position; the segregation from them of alaskite on the one hand, and hornblendite on the other, is additional evidence of this. The porphyritic forms, however, show generally two distinct generations, and this, with the fact that some of the phenocrysts of the first generation, especially the quartz, show corrosion and resorbtion, indicates a change of conditions; also the slight fluxional arrangement, sometimes observed, shows at least local movement. Yet the contemporaneity of the fine-grained porphyritic rocks with the granular forms, shows that the crystallization break registered by the former did not arise from any important change of position.

Composition of rocks. — The general mineral composition of rocks of all structures (leaving out the alaskite and hornblendite, which are plainly segregation products from the hornblende quartz-diorite), is the same, being a hornblende-quartz-diorite or quartz-andesite. In the andesites the quartz, where present, was plainly in process of resorbtion by the groundmass at the time of solidification, so that it is probable (from the fact the hornblende andesites and the hornblende-quartz-andesites often occur as variations of a single bed) that in those andesites which do not show free quartz the composition is the same as where they do, the quartz belonging to the first period of crystallization having been entirely resorbed.

Analyses of the rocks are as follows (analyst, Dr. H. N. Stokes):

No. 1, No. 117 N. Hornblende-biotite-quartz-diorite		No. 2, No. 120 N. Hornblende-quartz-andesite	
SiO_2	60.25	SiO_2	53.37
Al_2O_3	17.90	Al_2O_3	16.57
Fe_2O_3	3.08	Fe_2O_3	3.84
FeO	2.44	FeO	2.45
MgO	2.44	MgO	5.79
CaO	5.57	CaO	6.30
Na_2O	4.29	Na_2O	3.40
K_2O	1.89	K_2O	2.55
H_2O+	.20	H_2O+	.39
H_2O	1.24	H_2O	2.33
TiO_2	.65	TiO_2	.86
CO_2	none	CO_2	1.61
P_2O_5	.25	P_2O_5	.29
MnO	.06	MnO	.08
SrO	.07	SrO	trace
	100.33		99.83

In No. 1 the ratio of $Na_2O + K_2O : CaO = 1 : 1.1$. In No. 2 the same ratio is 1 : 1.13. These ratios are calculated from the quotient figures obtained by dividing the percentages of each by the molecular weights. Similarly in No. 1 the ratio of $K_2O : CaO$ is 1 : 4.95. In No. 2 the same ratio is 1 : 4.18.

No. 2 contains less quartz and more hornblende than No. 1, hence the decrease in silica and the increase in magnesia ; otherwise the two rocks are the same.

Correlation of rocks.—As before stated, just west of Mason's Butte lies the northern end of the Smith Valley and Pinenut ranges. On crossing from Waubuska through Churchill Canyon, andesites were found which were recognized in the field as similar to those in the butte. The bedding of these rocks is nearly horizontal. They are fine-grained hornblende-andesites, often with fine holocrystalline groundmass ; occasionally they vary to fine-grained diorite porphry. In higher portions of the mountains (these relatively coarse-grained lavas are exposed in the lowest cuts) the lavas are dacites and pyroxene andesites.

Andesites form the main mass of the Pinenut range at its northern end, which is separated from the Washoe district at

the southern end of the Virginia range by a comparatively narrow valley. The lavas of one range are evidently continuous with those of the other.[1] In the Washoe district have been found eruptions of hornblende-mica-andesite and quartz-andesite or dacite, corresponding exactly to that at Mason Butte. At Washoe, also, the andesite becomes, under favorable conditions, coarsely crystalline, and Messrs. Hague and Iddings[2] have noted that upon this complete crystallization quartz separates out, producing a mica-quartz-diorite.

RHYOLITIC ROCKS.

TRANSITIONS IN TEXTURE OF THE BASAL RHYOLITES OF THE PINENUT RANGE.

Field description.—The central core of the Pinenut range is made up of granitic rocks. These were examined in two localities: one southeast from Dayton, and one west from Wellington.

At the first mentioned locality, granitic rocks are exposed along an easterly facing scarp which is at the north end of Smith Valley. The rocks are all granular, so far as observed, but vary much in texture from fine to coarse; they are often porphyritic. They show a distinct banding, resembling at a distance rude stratification; this banding is due to a zonal arrangement of the rocks of different textures.

In the district west from Wellington, rhyolitie and granitic rocks are exposed in the spur just east from the Mountain House, and are of exceptional interest. Here, beneath the andesitic rocks which cover the mountain slopes, is found a highly indurated volcanic conglomerate and sandstone, apparently waterlaid, and consisting entirely of rhyolitic material. A short distance farther on, the rocks from which these detritals are derived were found in place. These original rocks show great variations, passing from a fine-grained, almost aphanitic,

[1] See "The Succession and Relation of Tertiary Igneous Rocks in the Great Basin Region," JOUR. GEOL., Vol. VIII, p. 621.

[2] Bull. 17, U. S. Geol. Surv.

rhyolite, to coarse siliceous granite and alaskite. The numberless variations are within a few feet of one another and are arranged in bands, recalling immediately the similar phenomenon in the andesitic rocks of Mason Butte. In the case of the rhyolitic rocks also there is no sign of intrusion of one into another, nor in general does there appear to be any marked gradations between the different bands at contact, the boundaries between them being fairly distinct.

It is clear in the field that the variations are chiefly textural and that the composition of all the varieties is nearly the same — that of siliceous granite or rhyolite.

In this case again, we have rocks which appear to represent the roots of old volcanics, being intermediate between completely massive plutonic igneous rocks and superficial fine-grained volcanics. They must have suffered a flowage resulting in the formation of this peculiar streaky structure, while the great variations in texture in the different bands show crystallization at points still far removed from the surface.

Of the different rock varieties in the locality west from Wellington the following will be briefly described.

Biotite-rhyolite (164 N^{a}.).—Structure porphyritic; groundmass cryptocrystalline, probably devitrified glass. The phenocrysts are of all sizes, the larger ones grading down to those which vanish in the groundmass. They are of feldspar, quartz, and biotite, the latter decomposed. The feldspar was determined to be largely albite and oligoclase-albite, although there is some orthoclase, The largest phenocryst of feldspar measures 2¾ ^{mm} in diameter; the largest one of the quartz, 1½ ^{mm}. The rock contains angular fragments of finer grain. Some of these seem to be devitrified rhyolitic glass, while others are fragments of more basic lava, probably andesite — these latter show small lath-shaped feldspar phenocrysts in a glassy semi-devitrified groundmass.

Biotite-rhyolite (165 N^{a}.).—In this specimen the groundmass becomes slightly coarser than in the preceding specimen and is very fine microgranular. It also becomes more scant than in

164 N^a, on account of the multiplication of phenocrysts, which show the same great variety in point of size as the rock just described. The same angular fragments of more basic lava also occur. The phenocrysts are quartz, orthoclase, and a striated feldspar; the latter tested twice by the Fouqué method proves to be albite. The orthoclase was optically determined as such.

Rhoylite (162 N^a.).—In this rock the groundmass is fine holocrystalline, coarse enough to enable one to distinguish the mosaic of quartz and feldspar. This groundmass contains the same fragments of more basic lava that have already been described, and also encloses broken phenocrysts of mostly unstriated feldspar.

Granite-porphyry, fine-grained (169 N.).—In this rock the groundmass is fine granular, sometimes granophyric, and conrists chiefly of quartz and orthoclase. The phenocrysts are abundant and consist of quartz and feldspar, with chlorite and epidote which are derived from the decomposition of ferromagnesian minerals. The feldspar phenocrysts are partly orthoclase and partly a striated feldspar, which, determined by the Foqué method, proves to be oligoclase-albite.

Biotite-granite, medium-grained (171 N.).—In this rock the grains are of two distincts sizes, one many times larger than the other. The larger grains have a tendency to idiomorphism, the smaller grains to allotriomorphism. The smaller grains are included between the interlocking larger ones and may be considered as forming an overgrown groundmass, partly crowded out by the multiplication and joining of phenocrysts, which are represented by the larger grains. The minerals of the rock are quartz, feldspar, biotite, and magnetite. The feldspar is almost entirely orthoclase, with some microcline and albite.

Granite, coarse (175 N.).—The structure of this rock is like that of the preceding, only coarser. It contains many perfect idiomorphic crystals of feldspar, often touching and almost interlocking, and smaller crystals of bleaching biotite and ragged pale green hornblende, the last perhaps secondary. These minerals

are in general cemented by a mesostasis of coarse allotriomorphic quartz, which often includes or is intergrown with, in poikilitic fashion, smaller crystals of feldspar, pale green hornblende, and sphene. The feldspar included in the quartz sinks to very small dimensions, whereas the ordinary feldspar grain is very large. The structure may be regarded as the coarsening of the porphyritic structure, or at least closely related to it by reason of the two generations. The large feldspar crystals are partly orthoclase, but are chiefly finely striated. Optical determinations of the striated crystals show microcline-anorthoclase and albite.

Granite, coarse (172 N.).—This rock is almost entirely like 175 N, and has a good deal of the peculiar structure of this rock, but in general is more hypidiomorphic granular or truly granitic.

Analysis of the structures of the granite-rhyolites.—The analysis of the structure of the granites and rhyolites just described helps toward a better understanding of their relation.

164 N (a). Here are phenocrysts of all sizes, gradually shrinking in size to the glassy (sometimes slightly devitrified) groundmass; *i. e.*, the crystallization, instead of belonging to one or two distinct generations, represents many generations, not separable from one another. This is a proof of gradual and equable hardening. It shows that the viscosity increased very slowly and regularly to the point of final complete solidification, the newer crystals having progressively smaller fields of crystallization.

165 N(a). This is like 164 N(a) except that the groundmass diminishes, on account of multiplication of phenocrysts. This marks a longer cooling period than 164 N(a), so long as almost to permit of total crystallization as relatively large crystals.

162 N(a). In this section the feldspar phenocrysts are not connected by gradual transitions with the groundmass, which is slightly coarser than that of 165 N(a) and is much more abundant. We have, therefore, two distinct generations of crystallization, and this, together with the frequently broken character

of the phenocrysts, indicates a break in the crystallization, evidently resultant from a movement of the solidifying mass. The order of events in this section was, therefore, (1) comparatively slow crystallization of feldspar; (2) flowage, producing a change of conditions; (3) medium rapid cooling, bringing about the uniform moderately fine crystallization of the rest of the rock.

169 N. Here the line between the abundant phenocrysts and the fine-grained groundmass is, in general, distinct, for although there are transitions between the two they are not so abundant as in rocks like 164 N(a) and 165 N(a). This connotes a shorter period of first crystallization (when the phenocrysts were formed) than does 165 N(a), then a more rapid cooling than 165 N(a) to a certain point, then a slower rate of crystallization, permitting the formation of the uniform fine granular structure.

171 N. The structure of this connotes a long period of slight viscosity, during which the crystals of quartz and feldspar could grow until they touched and sometimes interlocked. The difference in size between these crystals and the grains of the groundmass or mesostasis which fills the space between them, implies a slight break or change of conditions, after which was again a comparatively slow uniform crystallization of the rest of the rock, producing an even allotriomorphic granular structure. There are then two distinct generations of crystals. The resulting structure is entirely similar to the ophitic structure of diabases, save that in these siliceous feldspars the forms are not so elongated, and so the structure is not so striking. The structure of this specimen, however, differs from the typical granitic structure in the same way that a diabase differs in structure from a gabbro. A longer period for the first crystallization, reducing the mesostasis to a still smaller percentage, would give the aplitic structure, where the idiomorphic crystals are predominant and occupy the greater portion of the section.

175 N. This is like 171 N, but in general the mesostasis of comparatively small grains is wanting, being replaced by a filling of coarse allotriomorphic quartz. In this case the conditions of crystallization have evidently been gradual throughout. The

rock crystallized slowly under conditions of slight viscosity. After the exhaustion of the feldspathic material residual quartz crystallized in the remaining spaces.

Tabulation.—The following table shows the gradation from fine-grained rhyolite to granite:

Specimen No.	Character of groundmass.
164 N (a)	Glassy.
165 N (a)	Cryptocrystalline.
162 N (a)	Finely microgranular.
169 N	Microgranular; micropegmatic.
171 N	Granular; grains average .5^{mm} diameter.
172 N	Granular; grains average .5^{mm} diameter.
175 N	Large quartz grains, average 2.25^{mm}.

Analyses.—The following are analyses of the two fairly typical specimens as above described (analyst, Dr. H. N. Stokes):

(1) 168 N. Biotite rhyolite. Like 165 N (a).		(2) 172 N. Siliceous granite.	
SiO_2	71.49	SiO_2	75.09
Al_2O_3	15.06	Al_2O_3	13.51
Fe_2O_3	1.51	Fe_2O_3	1.13
FeO	.88	FeO	.08
MgO	.35	MgO	.18
CaO	1.54	CaO	.91
Na_2O	4.19	Na_2O	3.58
K_2O	3.39	K_2O	4.71
H_2O-	.16	H_2O-	.17
H_2O+	.88	H_2O+	.25
TiO_2	.20	TiO_2	.22
CO_2	none	Co_2	none
P_2O_5	.08	P_2O_5	.04
MnO	trace	MnO	trace
SrO	trace	SrO	trace
	99.73		99.87

It will be seen that No 2 is slightly more siliceous than No. 1; nevertheless the two rocks are intimately related. In No. 1 the relation of $K_2O + Na_2O : CaO = 1 : .26$. In No. 2 the same ratio equals $1 : .15$. Similarly, in No. 1 the relation of $K_2O : CaO = 1 : .75$. In No. 2 the same ratio equals $1 : .32$.

Conclusions.—Many of the bands in this granite-rhyolite series show by their structure that they have undergone no break

in crystallization from beginning to end. The rocks have evidently crystallized entirely in their present position, and the slow hardening which is ordinarily indicated shows that this point of consolidation was originally some distance from the surface.

In other specimens there have been slight breaks, bringing about two, three, or more generations of crystals which in the rocks near by are not distinguishable. These minor breaks were due to slight migrations of material in certain bands, which flowed slightly during the process of cooling, as is proved by the angular fragments of finer-grained lava which they contain and by the occasional broken condition of the phenocrysts.

As explanation of the difference in crystallization between the granular bands and the intercalated fine-grained ones, it must be remembered that those bands which were affected by flowage must have been at the time those possessing least viscosity and consequently those which were least crystallized. The final crystallization of these bands, therefore, took place at a later period than that of granular bands, at which period the rate of solidification was very likely more rapid. It is probable, moreover, that the movement of flowage brought on of itself a more rapid crystallization than if the rock had been undisturbed, and that thus the finer-grained groundmass orginated. The same suggestions hold good for the similar phenomena, already described at Mason Butte.[1]

[1] In connection with the conclusion above arrived at, *i. e.*, that the phenocrysts of the rocks were formed practically in place, compare the papers by Professor Pirsson and Professor Crosby. (*Am. Jour. of Sci.*, Vol. VIII, April, 1899, p. 271, "On the Phenocrysts of Intrusive Igneous Rocks," and *American Geologist*, Vol. XXV, No. 5, May, 1900, "On the Origin of Phenocrysts and the Development of Porphyritic Texture in Igneous Rocks.")

Professor Pirsson argues that the phenocrysts of intrusive rocks are not necessarily intratelluric, and that there is no necessity of more than one period of crystallization even for porphyritic rocks. From the fact that contact zones are often without phenocrysts, while the rest of the rock contains them; that in a contemporaneous complex of dikes and sheets some may have phenocrysts while others do not; from observed cases where fluidal phenomena show that phenocrysts have developed after the flowage; from the arrangement of the crystals of the groundmass around some phenocrysts, showing that these crystals have been crowded and shoved during the growth of the larger crystals; and from the fact that many granites (which have generally been considered intratelluric) contain very large phenocrysts, Professor Pirsson

TRANSITIONS OF TEXTURE IN THE GRANITE-RHYOLITES OF THE QUINN CANYON RANGE.

Field description.—The Quinn Canyon range lies a long distance east of all the other localities which have been described, being almost due south from Eureka and nearly west of Pioche. The whole southern portion of the range is buried in rhyolitic flows.[1] The range was examined by the writer at its northern end, where the Paleozoic core of the mountains emerge from the volcanic covering. On the western side of the range, near the contact of the Paleozoics with the rhyolite, the stratified rocks are pierced by numerous great dikes, which vary from coarse to fine in texture. These dike rocks seem similar in composition, and sometimes in texture, to the rather massive rhyolite which forms the hills to the west of this locality.

Microscopic description.—A specimen of the main rhyolite examined under the microscope has the following characteristics:

Rhyolite (241 N.).—This rock has phenocrysts of all sizes,

reasons that phenocrysts are not necessarily of a distinct crystallization period as compared with the groundmass, but may in some cases be formed in place. Professor Pirsson advances the explanation that a comparatively rapid fall of temperature and decrease of hydration, resulting in a viscosity augmenting in an increasing ratio, may produce monogenetic phenocrysts (that is, phenocrysts which occur only in a single generation). Recurrent phenocrysts (that is, those occurring in more than one generation) he explains as due to mass action, believing that minerals which are present in very large quantity are especially active crystallizers.

Professor Crosby believes that no sudden changes of temperature, hydration, or pressure, are necessary for the formation of phenocrysts. He believes that in a gradually consolidating rock the crystallization first established may be brought to a close by the gradually increasing viscosity and that after passing this critical point new zones of crystallization will be established, of much smaller field, and at this point the groundmass begins and the phenocrysts end. If the rate of cooling is still slower, an allotriomorphic granular texture results, while if the rate is more rapid the texture may be glassy or nearly so.

The deductions of the writer, given above, agree with those of the authors cited in this, that phenocrysts may be formed in place. His observations, however, go to show that where cooling is strictly uniform there will be no distinct generations, but a gradual transition from phenocrysts to groundmass; whereas, if there are distinct generations, they are brought about by breaks in the conditions of consolidation, even though these breaks be comparatively slight.

[1] G. K. GILBERT, *Survey West of the 100th Meridian;* Vol. III, Geology, p. 122.

from $1\frac{1}{2}^{mm}$ in diameter grading down into groundmass, which is cryptocrystalline, probably a devitrified glass.

Two selected specimens of the dike rocks have the following characteristics:

Biotite-granite-porphyry, near rhyolite (243 N.).—Like 241 N, this rock has phenocrysts of all sizes, from $1\frac{1}{2}^{mm}$ in diameter down to the groundmass. There are, however, more phenocrysts in this rock than in the one just described. As in 241 N, the phenocrysts have no fluxional arrangements, but a divergent one. The groundmass is fine holocrystalline allotriomorphic ganular.

Biotite-granite (242 N.).—This rock consists of grains of all sizes from $6\frac{1}{2}^{mm}$ in diameter down to the very minutest dimensions. The smallest ones, which are very abundant, are about .02 to .03^{mm} in diameter. There is a tendency to idiomorphism throughout. The smaller sizes of crystals act as mesostasis for the larger ones, and these have a mesostasis of the still smaller ones. The essential minerals are quartz, othoclase, and biotite, with accessory hornblende, titanite, magnetite, and a little striated feldspar.

Analyses.—The chemical composition of these rocks is as follows (analyst, Dr. H. N. Stokes):

(1) No. 214 N, Siliceous Rhyolite.		(2) No. 242 N, Biotite Granite.	
SiO_2	74.67	SiO_2	71.48
Al_2O_3	13.25	Al_2O_3	13.00
Fe_2O_3	1.06	Fe_2O_3	1.25
FeO	.18	FeO	1.55
MgO	trace	MgO	.95
CaO	1.26	CaO	2.60
Na_2O	3.99	Na_2O	2.60
K_2O	4.62	K_2O	4.24
H_2O-	.18	H_2O-	.20
H_2O+	.22	H_2O+	1.24
TiO_2	.07	TiO_2	.43
CO_2	.79	CO_2	.30
P_2O_5	.06	P_2O_5	.09
S	trace	S	none
MnO	none	MnO	.09
BaO	none	BaO	.09
SrO	none		
	100.35		100.11

In No. 1 the relation $K_2O + Na_2O : CaO = 1 : .2$. In No. 2 the same relation equals $1 : .53$. In the same way, in No. 1, $K_2O : CaO = 1 : .46$. In No. 2 the same ratio equals $1 : 1$.

Conclusions.—In the field the evident relation of the dikes to the rhyolite led to the inference that they had been the feeders of the extrusive rock. Under the microscope the composition of the three rocks is found to be the same, and the structure shows variations indicating no great differences in the conditions of cooling. The structure is identical with that of certain specimens of rhyolite-granite just described from the Pinenut range, and therefore need not be analyzed again. Briefly, in all three it indicates complete crystallization in one place, with no interrupting movement. The period of consolidation for 241 N was comparatively short, that of 243 N somewhat longer, and that of 242 N markedly greater than 243 N.

ANALOGOUS CASES OF VARIATIONS OF TEXTURE IN OTHER PARTS OF THE GREAT BASIN.

In the Washoe district, Nevada, not far from the first locality decribed by the writer, Messrs. Hague and Iddings[1] found a gradual transition from pyroxene andesites with glassy groundmass to pyroxene-diabase with coarse granular structure. In the Sutro Tunnel they found coarsening of the crystallization as the tunnel nears the core of Mount Davidson, so that at one end the rock may be called andesite and at the other end diabase. They also discovered like transitions between andesite and granular diorites.

Similarly they found that the earlier hornblende-andesite passes into diorite, while the later hornblende-mica-andesite changes into mica-diorite in such a way that the two rocks are inseparable. They concluded that a dike of so-called diabase is a variation of the basalt, which was one of the latest extrusions.

In short, according to these writers, the coarse holocrystalline rocks of the Washoe district are chiefly Tertiary, and are partly extrusive and partly closely connected with extrusives of similar

[1] Bull. 17, U. S. Geol. Surv.

composition. Another interesting conclusion is that the change between the lava texture and the granitoid texture consists chiefly in the coarsening of the groundmass.

In 1899, Messrs. Tower and Smith described textural transitions in the Tintic range in Utah, which lies within the petrographic province of the Great Basin and is situated southward from Great Salt Lake.[1] In this district is found pyroxene andesite or perhaps more properly latite, which is an effusive rock and is closely associated with granular monzonite. There are all variations of texture between andesite with glassy groundmass to that with a holocrystalline groundmass; from this to closely similar rocks, also with holocrystalline groundmass, which are called monzonite porphyry; and from these through panidiomorphic granular phases to those of hypidiomorphic granular structure.

CONCLUSIONS.

In the Great Basin, particularly in Nevada, we have Tertiary extrusive rocks which show transitions from a granular structure with glassy groundmass. The different phases are often intimately associated, and structural analysis shows that the differences of crystallization which brought about these variations were slight, a relatively small decrease of the rate of cooling being sufficient to allow the formation of the holocrystalline instead of the porphyritic structure.

Transitions similar to those found in the Great Basin have been sparingly chronicled elsewhere. These appear to become rare in proportion as the rocks become siliceous. This is so because with a given relatively rapid rate of cooling a magma of basic composition will consolidate with a holocrystalline structure, while a siliceous magma will become fine-grained and porphyritic. We have accordingly many instances of holocrystalline diabases which are certainly extrusive, and of similar rocks in rather fresher condition (generally due to their being younger) which have been called dolerites. In the more siliceous rocks such textural transitions are rare in

[1] *Nineteenth Ann. Rept. U. S. Geol. Surv.*, p. 656.

effusive bodies, but further down, at the roots of volcanoes, the conditions are such as to allow viscosity to increase with the same slowness that it does with a more rapid cooling rate in more basic rocks. Hence with increasing acidity we find the coarser grained varieties further removed from the surface. In general, however, it is plain that a granular rock is not necessarily a deep-seated one, in the formerly accepted sense of the word.

Another conclusion which may be made from the foregoing studies is, that the more important structures are not peculiar to particular rocks. The porphyritic and the coarse granular allotriomorphic or hypidiomorphic structures are already recognized as characterizing all rocks, of whatever chemical composition. Also the aplitic structure, or that in which idiomorphic minerals (which are the same as the phenocrysts of the porphyries) form the greater bulk of the rock, has been recognized as universal by Rosenbusch, who has described it in granitic rocks and in all intermediate ones down to gabbros; thus his rock terms include syenite aplite and gabbro aplite. The ophitic structure has been generally supposed to be characteristic of diabases, and without question is here best exhibited, on account of the rate of solidification which the basic composition of a magma entails and also because the elongated forms of the basic feldspars make the structure prominent. The foregoing studies, however, show that this structure is intermediate between the porphyritic and the aplitic structures, representing a stage in crystallization when the idiomorphic crystals (or phenocrysts, as they are called in the porphyries) have multiplied and grown so that they interlock; and that like these other structures it may occur in any rock. In the granites it is not so striking as in more basic rocks, on account of the blunt form of the alkaline feldspars which form the first generation of crystals, but it is nevertheless present in some of the granites which have been studied. In diorites the ophitic structure has been occasionally described.[1]

[1] ROSENBUSCH, *op. cit.*, p. 256; ZIRKEL, *Lehrbuch der Petrographie*, 2d ed., p. 483.

The writer, of course, interprets the term ophitic in its broader and not in its narrower sense, accepting it as meaning a structure where a network of interlocking, divergent, comparatively large feldspar crystals is filled in by grains of much smaller dimensions, whatever the nature of these grains may be. He does not interpret it as meaning that the mesostasis is necessarily augite. He finds grounds for this broader acceptation in the writings of Rosenbusch, Zirkel, and others. Rosenbusch applies the term ophitic[1] to diabases where the mesostasis is not augite, but an aggregate of primary quartz and feldspar.

Therefore, the glassy, fine porphyritic, coarse porphyritic, ophitic, aplitic and hypidiomorphic granular structures may occur in any rocks. They pass by gradual transitions into one another and are dependent upon relatively very slight differences in conditions of cooling. All may be formed without any marked migration of the consolidating rock.

These conclusions are important in considering rock classification, as showing that structure cannot be made the element of greatest importance. Granites, granite porphyries, granite aplites and rhyolites, for example, must not be separated, but put as closely together as possible, and the same is true of diabases, diabase porphyrites, diabase aplites, and basalts.

J. E. Spurr.

[1] *Mikroskopische Physiographie*, 3d ed., p. 1117.

THE FOYAITE-IJOLITE SERIES OF MAGNET COVE: A CHEMICAL STUDY IN DIFFERENTIATION.

INTRODUCTORY.

Sometime since I published a paper[1] on the "Igneous Complex of Magnet Cove," in which it was shown that the main types found there were arranged in a very regular series from the center to the periphery of the mass, and that this was an excellent example of the differentiation of a magma in place, presenting, however, the anomaly of being less "basic" at the borders than at the center. It was also remarked that the analyses then available "vary continuously in one direction, with scarcely a break or abnormality of any kind."[2]

Since then several considerations led to the belief that a new and more detailed chemical examination of the main rock types was desirable. Several of these, notably the "leucite-porphyry" and ijolite, are representatives of rock groups of great theoretical importance, complete analyses of which are highly desirable. In this respect many of those published by Williams[3] are defective, the non-determinations of the rarer constituents being largely due to the fact that the importance of completeness in rock analysis was not recognized at the time they were made.[4]

Such a reëxamination seemed to be the more desirable, since in a recent paper Pirsson[5] has shown that the rocks occurring in the Little Belt Mountains of Montana form an extremely regular series. By plotting the constituent oxides on an abscissal basis of distance from the center of the mass, he arrived at the conclusion in this case that, "given the percentage of one element, the chemical composition of any rock of the series to within a

[1] *Bull. Geol. Soc. Amer.*, Vol. XI, p. 389, 1900. [2] *Op. cit.*, p. 403.

[3] J. F. Williams, "Igneous Rocks of Arkansas." *Ann. Rep. Geol. Surv. Ark.* Vol. II, 1890.

[4] *Cf.* J. C. Branner, in Williams, *op. cit.*, p. xiv.

[5] L. V. Pirsson, *Twentieth Ann. Rep. U. S. Geol. Surv.*, Part II, p. 569 ff., 1900.

fraction of 1 per cent. can be deduced from the diagram." This instance is the first in which the differentiation of a mass of magma is rendered capable of exact mathematical treatment and proof, and its great theoretical interest and importance is obvious. The conditions of the locality were such that it was thought that the Magnet Cove complex might furnish another favorable example of the same kind, a hope which was justified by the results obtained, as will be seen later.

The analyses of six of the representative plutonic rocks of Magnet Cove, as well as two of Fourche Mountain, were therefore undertaken, with the determination of the rarer constituents which might be present. For petrographic descriptions the reader is referred to the two papers cited above.

In this connection I would express my full endorsement of Pirsson's remarks[1] on the importance of good and complete analyses, which are absolutely essential for such mathematical discussion, and with him deplore their comparative rarity. To many petrographers, any collection of figures which foots up within 98 and 102 per cent. is a usable analysis, even though the results are at variance with the mineralogical composition, and some of the obviously important constituents are not estimated. It is not realized that such "analyses" do far more harm than good to the science. From this point of view alone, the excellent work of Dr. Hillebrand and the other chemists of the United States Geological Survey is of inestimable value, as they have set a standard to fall short of which in any marked degree should be accounted a petrographic sin. Let me be the first to confess "*peccavi.*"

ANALYSES.

Pulaskite.— The specimen of this type was collected at the Little Rock Granite Company's quarry, at Fourche Mountain, near Little Rock, the type locality. In I is given my analysis, in II that of R. N. Brackett, as quoted by Williams. The two do not differ materially, I showing rather less Fe_2O_3 and CaO and more FeO, MgO, and alkalis, though the ratio of

[1] L. V. Pirsson, *op. cit.*, p. 578.

	I	II		I	II
SiO_2	60.20	60.03	TiO_2	0.14	....
Al_2O_3	20.40	20.76	ZrO_2	trace	....
Fe_2O_3	1.74	4.01	P_2O_5	0.15	0.07
FeO	1.88	0.75	SO_3	0.13	....
MgO	1.04	0.80	Cl	0.09	....
CaO	2.00	2.62	S	none	....
Na_2O	6.30	5.96	MnO	trace	trace
K_2O	6.07	5.48	BaO	trace	....
$H_2O(110^\circ+)$	0.23	0.53			
$H_2O(110^\circ-)$	0.10	0.06		100.47	101.07
C_2O	none	....			

I. Pulaskite, Fourche Mountain. Washington, analyst.

II. Pulaskite, Fourche Mountain. Brackett, analyst. WILLIAMS, *op. cit.*, p. 70.

$Na_2O:K_2O$ is about the same in both, being 1.57 in I and 1.66 in II. The specimen analyzed by Brackett apparently contained a little more acmite, though the variations are scarcely more than are to be expected in different specimens from the same mass.

Analysis I can be calculated out as below. There is apparently an excess of Al_2O_3, amounting to about 4 per cent. in this, as well as in II, which it is difficult to account for. It does not seem to be due to kaolinite or hydronephelite, as the rock is too fresh, and there is no muscovite present. Such an excess of Al_2O_3 above $(Na_2O+K_2O) - Fe_2O_3$ may be observed in many analyses of nephelite-syenites, if the Fe_2O_3 is calculated as acmite, and no anorthite molecule is assumed to be present. Among these are some by Hillebrand, and there is no reason to suppose that this peculiarity is due to errors of analysis. It is a feature of this group of rocks which seems to call for investigation, and may possibly be connected with the occurrence of corundum in the nephelite-syenites.

Orthoclase	35.1
Albite	39.8
Nephelite	3.1
Sodalite	1.2
Aegirite	5.1
Hornblende, diopside, and biotite	11.0
Apatite	0.5
Extra alumina	4.2
	100.0

Pulaskite (*Foyaite*).—This is Williams's "gray granite," the specimen coming from Braddock's quarry, on Fourche Mountain. My analysis is given in I below, with that of W. A. Noyes as quoted by Williams in II. The two are closely alike in all

	I	II		I	II
SiO_2	60.13	59.70	CO_2	none	....
Al_2O_3	20.03	18.85	TiO_2	1.15	....
Fe_2O_3	2.36	4.85	ZrO_2	0.05	....
FeO	1.33	....	P_2O_5	0.06	....
MgO	0.76	0.68	SO_3	0.14	....
CaO	0.87	1.34	MnO	trace	....
Na_2O	6.30	6.29	BaO	trace	....
K_2O	5.97	5.97			
H_2O (110°+)	1.41	1.88		100.72	99.56
H_2O (110°−)	0.16	....			

I. Pulaskite, Braddock's quarry, Fourche Mountain. Washington, analyst.
II. Pulaskite ("Foyaite"), same locality. Noyes, analyst. WILLIAMS, *op. cit.*, p. 81.

respects except Al_2O_3, which is about 2 per cent. higher in I, as about 1 per cent. of TiO_2, and a trace of P_2O_5 must be deducted from the Al_2O_3 of II.

The analysis (1) calculates out as follows, and it is evident that there is no essential difference between this rock and the last mentioned.

Orthoclase	28.6
Albite	39.0
Nephelite	6.2
Nosean	1.2
Kaolin	7.5
Aegirite	6.9
Biotite	7.9
Titanite	2.7
	100.0

Foyaite.—What seemed to be an average specimen of the occurrence at Diamond Jo quarry, Magnet Cove, was chosen for analysis. No pyrite was visible, though the analysis shows a trace of sulphur. One or two small garnets were seen in one section, which mineral is not mentioned by Williams as an accessory.

Apart from the determination of minor constituents, my analysis (I) does not differ materially from that of Brackett

	I	II	I	II	
SiO_2	53.09	53.38	TiO_2	0.11	....
Al_2O_3	21.16	20.22	ZrO_2	0.04	....
Fe_2O_3	1.89	1.56	P_2O_5	0.15	....
FeO	2.04	1.99	SO_3	none	....
MgO	0.32	0.29	Cl.........	0.02	....
CaO	3.30	3.29	S..........	0.08	1.77[1]
Na_2O	6.86	7.89	MnO.......	0.20	trace
K_2O	8.42	6.21	BaO.......	0.61	....
$H_2O(110°+)$	1.13				
$H_2O(110°-)$	0.24	3.43		100.48	100.03
CO_2	0.82				

I. Foyaite, Diamond Jo quarry, Magnet Cove. Washington, analyst.

II. Foyaite, same locality. Brackett and Smith, analysts. WILLIAMS, Sp. gr. 2.599 at 26°C., *op. cit.*, p. 238.

and Smith (II), except in the presence in the latter of nearly 2 per cent. of pyrite, and in the alkalis. I gives a ratio of $Na_2O : K_2O$ of 1.3, while in II it is 1.92. The amount of BaO in I is high, and is noteworthy since it is found only in traces or not at all in the other rocks. It probably belongs with the abundant orthoclase, since other cases are known of BaO partially replacing K_2O in the feldspar of alkaline rocks. The analysis calculates out thus:

Orthoclase -	51.8
Nephelite - -	20.3
Cancrinite -	13.1
Aegirite - -	5.7
Diopside - -	8.6
Titanite and pyrite -	0.5
	100.0

It is seen that this bears out Williams's remark that "the orthoclase is perfectly free from isomorphous mixtures of other feldspars." It is indeed somewhat remarkable that the albite molecule should be entirely lacking, or almost so, in a rock containing so much soda. It seems to be characteristic of the

[1] FeS_2.

Magnet Cove rocks that albite, as well as anorthite and hornblende, are of very limited occurrence.

Covite (*"Shonkinite"*).—The specimen of this rock, which is Williams's "fine grained syenite," came from below the schoolhouse on the western border of the Cove, and the analysis was published in my former paper. It is repeated here, with the addition of P_2O_5, which has been determined since. Several analyses of analogous rocks are also given.

	I	II	III	IV	V
SiO_2	49.70	44.65	47.61	48.98	46.99
Al_2O_3	18.45	13.87	14.26	12.29	17.94
Fe_2O_3	3.39	6.06	4.90	2.88	2.56
FeO	4.32	2.94	4.07	5.77	7.56
MgO	2.32	5.15	2.62	9.19	3.22
CaO	7.91	9.57	8.71	9.65	7.85
Na_2O	5.33	5.67	6.70	2.22	6.35
K_2O	4.95	4.49	4.08	4.96	2.62
H_2O (110°+)	1.09	2.10	1.89	0.56	0.65
H_2O (110°−)	0.25	0.95	0.26	0.26	....
CO_2	....	0.11	....	....	....
TiO_2	1.33	0.95	1.38	0.98	0.94
ZrO_2	....	....	0.18	....	....
P_2O_5	0.40	1.50	1.38	0.98	0.94
SO_3	....	0.61	....	....	....
Cl	....	trace	0.37	....	....
F	....	....	trace	0.22	....
S	....	....	0.03	....	....
MnO	trace	0.17	0.30	0.08	trace
BaO	....	0.76	0.41	0.43	none
SrO	....	0.37	0.36	0.08	....
	99.44	99.99	100.68	99.99	99.60

I. Covite, Below Schoolhouse, Magnet Cove. Washington, analyst. *Bull. Geol. Soc. Amer.*, Vol. XI, p. 399, 1900.

II. Theralite, Gordon's Butte, Crazy Mountains, Montana. Hillebrand, analyst. J. E. Wolff, *Bull. No. 150* U. S. Geol. Surv., p. 201, 1898.

III. "Tinguaite," Two Buttes, Colo. Hillebrand, analyst. *Bull. 148* U. S. Geol. Surv., p. 182, 1897.

IV. Shonkinite, Yogo Peak, Little Belt Mountains, Montana. Hillebrand, analyst. Weed and Pirsson, *Am. Jour. Sci.*, Vol. L, p. 474, 1895.

V. Essexite, Salem Neck, Mass. Washington, analyst. Jour. Geol., Vol. VII, p. 57, 1899.

The mineralogical composition of these rocks is such that their calculation must, of necessity, be arbitrary and only

approximate, but those of I, II, IV, and V may be very roughly reckoned out, as below, that of IVa being Pirsson's calculation.

	Ia	IIa	IVa	Va
Orthoclase	29.3	29	25	16.3
Albite	22.8	..	10	13.3
Anorthite	....	..		17.2
Nephelite	9.0	23	..	20.1
Haüyne	....	4	..	....
Aegirite	4.5	4	..	3.7
Diopside	9.0	25	35	3.7
Hornblende	18.8	..	5	7.2
Biotite	....	..	18	....
Olivine	....	2	7	9.2
Magnetite	2.5	7	..	4.3
Titanite	3.1	2	..	4.0
Apatite	1.0	4	..	1.0
	100.0	100	100	100.0

In my former paper I discussed briefly the position of this rock in classification, and provisionally put it with the shonkinites. At that time the mineralogical composition had not been calculated, and this position was assigned to it because it resembled Pirsson's shonkinites, except in the presence of nephelite and of hornblende instead of biotite, and also because it came under Rosenbusch's definition[1] of these rocks, whose essential features according to him, are the presence of abundant dark minerals along with nephelite and orthoclase. As was also remarked, it cannot be put with the essexites or theralites (although chemically closely resembling these), on account of the lack of plagioclase.

In this connection it is of great interest to note the fact that, in his latest description[2] of typical theralite, J. E. Wolff states that there is nothing which can strictly be called soda-lime feldspar present. Indeed this fact is evident from a consideration of the analyses by Hillebrand, published in the same place. The name theralite, therefore, cannot be applicable to Wolff's Montana rocks, or else its definition must be changed.

[1] ROSENBUSCH, *Elemente der Gesteinslehre*, p. 174, 1898.

[2] *Bull. U. S. Geol. Surv.*, No. 150, p. 197, 1898.

It will be seen that, though the covite and the theralite of Wolff resemble each other in qualitative mineralogical composition, as both are composed essentially of alkali-feldspar, nephelite and ferromagnesian minerals, and that both are distinctly leucocratic in character, yet that in a quantitative mineralogical way they are decidedly different. The feldspathic constituents of the covite are very largely feldspar, with only accessory amounts of nephelite, while the theralite shows about as much feldspathoid as feldspar. The calculation of the latter cannot be exact, since some of the soda goes into the feldspar, but this must be small, and cannot affect the result to any great extent. It is evident, then, that the name of theralite is not appropriate for the Magnet Cove rock, though it might be used in the present very vague and loose method of classification, based largely on qualitative mineralogical composition.

A comparison of Pirsson's descriptions[1] with Rosenbusch's definition of shonkinite indicates that the latter has been apparently laboring under a misapprehension of the former's descriptions, and that his definition does not cover the rocks as Pirsson described them. Pirsson expressly states in each case that nephelite is either entirely absent or present only in mere traces, which does not coincide with the definition which makes nephelite an essential constituent.

Although resembling each other in many ways, yet there are certain striking differences between the analysis of the Magnet Cove rock and those of shonkinite. In SiO_2, iron oxides, CaO and K_2O they are closely alike, but in the Magnet Cove rock Al_2O_3 and Na_2O are higher and MgO lower. Indeed the calculations of the mineralogical composition, though that of Ia is only approximate, show clearly that while the "covite" is distinctly leucocratic the shonkinite is as decidedly melanocratic. A similar distinction will be pointed out between the "leucite-porphyry" and missourite. In this respect the rock under consideration resembles the typical essexite, though here again there is a distinct difference in the amount of K_2O, in the essexite this being

[1] L. V. Pirsson, *Bull. Geol. Soc. Am.*, Vol. VI, p. 408, 1895; *Am. Jour. Sci.*, Vol. L, p. 474, 1895; *Am. Jour. Sci.*, Vol. I, p. 358, 1896.

much lower, and plagioclase entering to a very considerable extent.

For this leucocratic holocrystalline combination of orthoclase (alkali-feldspar) and less nephelite, with hornblende and aegirite-augite, of granitic structure, and with a composition like that given in the analysis above, I would propose the name of Covite. If only the qualitative, not the quantitative, mineralogical composition be considered, the covites may be called basic nephelite-syenites or foyaites. But the whole tendency of modern petrography is, rightly, against this narrow view of rock classification, and the use of a new name seems to be abundantly justified. In ordinary typical foyaites the alkali-feldspars and nephelite, etc., make up from 75 to 90 per cent. of the rock, the dark minerals consequently only from 10 to 25 per cent. In the covites, on the other hand, while the type is rather leucocratic, the light and dark minerals are present more nearly in the same amount, and these rocks might justly be called "mesocràtic."

As a matter of fact, accepting Pirsson's definition of shonkinite as the standard (viz., melanocratic combination of alkali-feldspar with pyroxene, etc.), the covites are the rocks which correspond to Rosenbusch's definition of shonkinite. A similar rock, which also belongs here, is that the analysis of which is given in III, and which Cross provisionally called a "tinguaite."

Arkite (*"Leucite-porphyry"*).—The specimen which was selected for analysis came from an exposure a little to the northeast of and above Diamond Jo quarry. Judging from the other specimens which I collected around the area, it seemed to be representative and an average specimen of the occurrences. A good sized hand specimen was used for the analysis, so as to obtain a fair sample of this rather coarsely porphyritic rock.

The results, given in I, were rather surprising in comparison with the analysis by W. A. Noyes of another specimen from the neighborhood (II). Not only is SiO_2 much lower, but MgO is a little higher, CaO much more so, and, though the total amount

of alkalis remains the same, the new analysis shows a rock relatively richer in potash as compared with soda.

	I	II	III		I	II	III
SiO_2	44.40	50.96	46.06	ZrO_2	0.03	....	....
Al_2O_3	19.95	19.67	10.01	P_2O_5	0.37	....	0.21
Fe_2O_3	5.15	7.76	3.17	SO_3	0.06	trace	0.05
FeO	2.77	.....	5.61	Cl	trace	0.25	0.03
MgO	1.75	0.36	14.74	MnO	0.08	trace	trace
CaO	8.49	4.38	10.55	BaO	0.01	....	0.32
Na_2O	6.50	7.96	1.31	SrO	....	....	0.20
K_2O	8.14	6.77	5.14				
H_2O (110°+)	1.17	1.38	1.44		100.76	100.01	99.57
H_2O (110°−)	0.24	.....	.....	Less O = Cl	......	0.06	0.01
CO_2	0.12	.....	.....				
TiO_2	1.53	0.52	0.73		......	99.95	99.56

I. Arkite, Magnet Cove. Washington, analyst. Sp. gr., 2.770 at 26° C.

II. Arkite, Magnet Cove. Noyes, analyst. WILLIAMS, *op. cit.*, p. 276.

III. Missourite, head of Shonkin Creek, Highwood Mountains, Montana. Hurlbut, analyst. WEED and PIRSSON, *Am. Jour. Sci.*, Vol. II, p. 321, 1896.

The discrepancy between the two analyses of the leucite rock cannot be explained by the supposition that the specimen analyzed by Noyes carried a larger proportion of pseudo-leucite, since, although the other constituents work out well on this basis, the amount of K_2O in II is not intermediate between that in I and in Williams' analysis of a pseudo-leucite crystal. It seems to be the case that Noyes' specimen represents a slightly different phase, possibly richer in aegirite, but poorer in diopside and garnet. From my own observations in the field and the specimens collected, I conclude that the specimen of I represents the normal rock more closely than that of II.

It may be remarked that this supposition is borne out by the fact that analysis I is, in a general way, intermediate between that of the covite and that of the ijolite, given later, while Noyes' is not. This is to be expected in view of the observation noted in my former paper (p. 395), that "while the relations of the 'fine grained' (shonkinitic) syenite to the leucite-porphyry are uncertain, the former lies apparently outside or above the latter."

In the absence of discrimination between the two iron oxides

in II, it is impossible to make a satisfactory calculation of Noyes' analysis, but No. I works out thus, the result being only an approximation, owing to the composition of the rock. In IIIa is given that of the missourite, as calculated by Pirsson.

	Ia		IIIa
Orthoclase	3.9	Leucite	16
Leucite	36.9	Analcite	4
Nephelite	25.5	Zeolites	4
Aegirite	8.4	Augite	50
Diopside	10.8	Olivine	15
Garnet	14.5	Biotite	6
		Iron ore	5
	100.0		100

It is evident from this table that while both rocks are alike in being composed essentially of leucite, with subordinate nephelite (or zeolites), and dark minerals, yet that they differ radically from each other, just as did the covite and shonkinite. The Magnet Cove rock is distinctly leucocratic, carrying about 66 per cent. of light minerals, while the missourite is as decidedly melanocratic, carrying only 24 per cent. of these.

It is obvious from the mineralogical composition, as well as from the analysis, that the name "syenite" which has been applied to this rock is not justified, if this term is to retain any precision of meaning except that of indicating the absence of quartz and an alkaline character. Since this is so, and since the rock represents a most interesting and quite distinct type, it certainly should have a distinct appellation of its own.

It would seem peculiarly appropriate to honor the memory of its first describer, J. F. Williams, by calling it Williamsite. But since this name has been already preëmpted by Shepard for a variety of serpentine, and as it would be a solitary exception among rock names, it will be best not to do so. I propose, therefore, the name of "arkite" (from the usual abbreviation of the state name Arkansas), the essential features being a holocrystalline, porphyritic, leucocratic combination of leucite (or pseudo-leucite) and nephelite, with pyroxene and garnet.

Ijolite.—The analysis of this type, from below Dr. Thornton's, has been already published,[1] but is here repeated, with the addition of several constituents which have been determined since. In II is given the analysis of a typical ijolite from Iiwaara, in Finland. The two do not differ materially, except that I is higher in CaO and correspondingly lower in Na_2O.

	I	II		I	II
SiO_2	41.75	43.70	CO_2	none	....
Al_2O_3	17.04	19.77	TiO_2	0.58	0.89
Fe_2O_3	6.35	3.35	ZrO_2	0.05	....
FeO	3.41	3.94	P_2O_5	1.09	1.34
MgO	4.71	3.94	S	none	....
CaO	14.57	10.30	MnO	trace	trace
Na_2O	6.17	9.78	BaO	none	....
K_2O	3.98	2.87			
$H_2O(110°+)$	0.62	0.89			
$H_2O(110°-)$	0.28			100.60	100.30

I. Ijolite, Magnet Cove. Washington, analyst. *Bull. Geol. Soc. Am.*, Vol. XI, p. 399, 1900. Sp. Gr. 3084—26°C.

II. Ijolite, Iiwaara, Finland. Sahlbom, analyst. V. HACKMAN, *Bull. Com. Geol. Finl.*, No. 11, p. 17, 1900.

The mineralogical composition of the two is given below, that of IIa being Hackman's calculation. II is almost exactly half nephelite, while I contains rather less than half of this mineral, but both may reasonably be called mesocratic. Hackman's specimen did not contain any garnet, but this is a very

	Ia	IIa[2]
Nephelite	38.7	55.00
Aegirite	4.6	7.15
Diopside	31.3	33.22
Augite	6.9	.....
Melanite	15.3	.....
Titanite	....	2.16
Apatite	3.0	3.17
	100.0	100.70

[1] H. S. WASHINGTON, *op. cit.*, p. 399.

[2] There is a clerical error in Hackman's results, as he gives the nephelite as 51.02, the sum as 100.50.

variable constituent in the Finland ijolites. Hackman (*op. cit.*, p. 4) notes the identity between the Magnet Cove rock and the Finland and Alnö ijolites.

Biotite-ijolite.—An analysis was also made of this rock, the specimen coming from near the Baptist church, and the results are given in I. My specimen was, unfortunately far from fresh, so that the figures are of little value. Williams' analysis (II) of the same type, undoubtedly made on fresher material, is to be preferred. The chief feature of interest in I is the (for this oxide) large amount of ZrO_2, which may be correlated with the neighboring "eudialyte-syenite pegmatite" described by Williams.

	I	II		I	II
SiO_2	38.11	38.93	SO_3	none	....
Al_2O_3	20.84	15.41	Cl	....	0.02
Fe_2O_3	5.67	5.10	S	0.14	0.89[1]
FeO	1.46	4.24	MnO	0.14	trace
MgO	3.80	5.57	BaO	trace	....
CaO	14.44	16.49	SrO	....	trace
Na_2O	6.65	5.27	Li_2O	....	trace
K_2O	2.12	1.78			
H_2O(110°+)	4.51	5.20		100.60	100.87[2]
H_2O(110°−)	0.57		Less O	0.04	
CO_2	0.65	....			
TiO_2	0.48	1.62		100.56	
ZrO_2	0.18	....	Sp. Gr.	2.679—26° C.	
P_2O_5	0.84	0.35			

The composition of the rock is such that any calculation of the mineralogical composition must be rather arbitrary and unsatisfactory, but the following (IIa) represents roughly and

	IIa.
Orthoclase	4.8
Nephelite	24.1
Biotite	6.2
Diopside	30.6
Melanite	23.0
Schorlomite	6.7
Magnetite	3.6
Apatite	1.0
	100.0

[1] FeS_2. [2] Williams gives 100.57.

approximately that of Williams' specimen. It is probable that my specimen was rather richer in nephelite and poorer in dark minerals than Williams'. The composition is much the same in a general way as that of the ijolite, only that it is melanocratic, rather than mesocratic.

Jacupirangite.—A new analysis was made of the dark, coarse-grained rock, composed largely of augite, which occurs as a small mass northeast of the main area, on Cove Creek. This was deemed to be advisable since the analysis of Williams showed more CaO, or less MgO and FeO, than was necessary to form augite or any other mineral present. The analysis of Williams is given in I, and my results in II, with two other analyses for comparison.

No.	I	II	III	IV
SiO_2	36.51	38.39	38.38	45.05
Al_2O_3	8.22	7.05	6.15	6.50
Fe_2O_3	8.29	9.07	11.70	3.83
FeO	3.31	6.17	8.14	7.69
MgO	8.19	11.58	11.47	12.07
CaO	18.85	19.01	18.60	18.82
Na_2O	2.10	0.74	0.78	0.94
K_2O	1.08	0.75	0.13	0.78
H_2O 110°+	1.40	0.33	0.54	2.40
H_2O 110°−	....	0.14	0.18	
CO_2	....	0.32	none	....
TiO_2	3.11	4.54	4.32	2.65
ZrO_2	....	none	....	....
X		0.24	....	....
P_2O_5	....	0.82	0.17	0.15
Cl	0.03[1]	....	....	....
S	6.03	0.42	....	....
MnO	trace	0.32	0.16	....
BaO	....	trace	....	....
SrO	trace	....	....	....
	99.22	99.89	100.72	100.88

Sp. gr., 3.407—26° C.

I. Jacupirangite, Magnet Cove. J. F. Williams, analyst. *Op. cit.*, p. 227.
II. Jacupirangite, Magnet Cove. H. S. Washington, analyst.
III. Jacupirangite, Jacupiranga, Sao Paolo, Brazil. H. S. Washington, analyst.
IV. Pyroxenite, Brandberget, Gran, Norway. L. Schmelck, analyst. W. C. Brögger *Q. J. G. S.*, Vol. L, p. 31, 1894.

[1] FeS_2.

While I and II are alike in a general way, yet there are marked differences in SiO_2, FeO, MgO and S. The specimen analyzed by Williams carries considerable pyrite, while mine only showed a few specks of it. The differences in the other constituents named may be attributed to alteration, especially in view of Williams' statement that the specimen analyzed by him was not fresh.[1] Analysis II calculates out readily as follows :

	IIa
Nephelite	4
Diopside	64
Augite	15
Biotite	5
Magnetite	8.7
Pyrite	0.7
Calcite	0.6
	100.0

In my former paper this pyroxenite was referred somewhat doubtfully to the jacupirangite of Derby. Through the kindness of this gentleman, to whom I would express here my deep acknowledgments, I have lately received numerous specimens of the Brazilian types. A comparison of these with the Magnet Cove specimens makes it evident that the two occurrences differ chiefly in size of grain, the Arkansas rock being very coarse, while those from Brazil are much finer grained. In all other essential respects the two are closely alike.

From the microscopical examination of the specimens which Professor Derby sent me, it is evident that the "Jacupirangites" of Brazil vary from rocks rich in nephelite, and which are true ijolites, closely analogous to those of Magnet Cove and Finland, through rocks composed predominantly of pyroxene, with small and varying amounts of magnetite and nephelite, to types extremely rich in magnetite and with no nephelite or only traces of this mineral. Accepting then the name of Jacupirangite for the medium type, the application of this name to the Magnet Cove rock is abundantly justified, since the only difference is the comparatively unimportant one of size of grain, both being holocrystalline.

[1] WILLIAMS, *op. cit.*, p. 227.

That this identity of the two, based on mineralogical grounds, is correct, is substantiated by a chemical analysis of one of Derby's specimens made by myself. For this purpose an apparently medium specimen was chosen, composed largely of a violet-brown augite, with some magnetite (more than in the Arkansas rock) and only a little nephelite (less than in the other). No biotite was present, and only traces of apatite. This analysis, given in III of the table, is most remarkably close to that of the Magnet Cove jacupirangite in all respects, except the iron oxides. Indeed the figures for silica, magnesia, lime, soda, water, titanic acid and manganese are close enough to belong to duplicate analyses of the same specimen, and those for alumina and potash do not differ greatly. The higher iron oxides are of course connected with the more abundant magnetite, but, apart from this, the mineralogical composition is closely similar.

The closest known analogue of these rocks is probably the pyroxenite of Brandberget, an analysis of which is given in IV above. The only noteworthy differences are in SiO_2 and Fe_2O_3. That of the former apparently conditioned the formation of nephelite in the Magnet Cove and Brazil rocks and plagioclase at Brandberget, while the higher ferric oxide of II and III is to be connected partly with the more abundant magnetite in the former.

Henry S. Washington.

[*To be continued.*]

THE PRE-TERRESTRIAL HISTORY OF METEORITES.

The completion of the studies for students relating to the composition and structure of meteorites, which have recently been published in this Journal, furnishes an opportunity for me to record certain deductions which seem to me warranted by the facts there presented, but which, being largely theoretical, had best be stated as the expression of individual opinion.

That theories of the origin and cosmic history of meteorites have been propounded before, and that these have varied widely in character, the present writer is well aware. These theories may be mentioned at the outset, together with the names of those who have given them special support, without, however, entering into any discussion of the merits of each.

Meteorites have been declared to be (1) terrestrial matter discharged into space by the volcanoes of the earth and returned to it again (Sir Robert Ball); (2) matter discharged from the volcanoes of the moon (La Place, J. Lawrence Smith); (3) matter ejected from the sun (Sorby); (4) portions of shattered stars (Meunier); (5) portions of a shattered planet (Boisse); (6) portions of comets (Newton); (7) clouds of gas or dust cemented and solidified by the action of the earth's atmosphere (Brezina).

All of these hypotheses have been urged by men of eminence, each urging strong reasons for his views. These reasons can be learned by study of the original authorities, and the discussion of them in the present article is not a part of my purpose. I shall endeavor here simply to present my own views and my reasons for the same.

The study of meteorites has shown that:

1. The majority of iron meteorites are octahedral.

2. The majority of stone meteorites are chondritic, and contain considerable glass.

3. Between iron and stone meteorites there is every gradation—they are formed of the same sort of matter.

The above statements would probably not be questioned by any authorities of the present day. The following, however, might not be agreed to by all :

4. The substance of meteorites was in a solid state before the fall of these bodies to the earth.

5. The structure of the majority of meteorites shows that their substance has cooled from a liquid or semi-liquid condition to that of a solid.

6. The structure of the majority of iron meteorites shows that the change from a liquid or semi-liquid to a solid state has taken place slowly.

7. The structure of the majority of stone meteorites shows that the change from a liquid or semi-liquid to the solid state has taken place rapidly.

The four latter statements may then be briefly discussed, and important known objections to them stated.

Concerning statement 4: It was suggested by writers in the early part of the last century that meteorites were concretions formed in our own atmosphere. Brezina inclines to accept this view with the modification that the substance of meteorites was extra-terrestrial, but that it arrived at the earth in the shape of gas or dust and was cemented or solidified by the earth's atmosphere. To my own mind, the slickensided surfaces and veins exhibited by many meteorites afford sufficient contradiction of such a view, and compel the conclusion that the matter in which such structures occur had existed in a solid state for a considerable length of time before it reached the earth.

Concerning statement 5: Several writers, but especially Daubree,[1] have expressed the conviction that the substance of meteorites gives evidence of having passed directly from a gaseous or vaporous state to that of a solid. The opinion seems to be based chiefly on Meunier's synthetic experiments, in which he succeeded in reproducing mineral aggregations having the composition of meteorites and somewhat resembling them in structure, by the inter-action of vapors.[2] But, as pointed out by Cohen,[3] the absence of gas and vapor pores in meteorites

[1] "Observations sur les conditions qui paraissent avoir preside a la formation des meteorites," *Comptes Rendus*, 1893, CXVI, pp. 345–7.

[2] *Encyclopedie Chimique*, Tome II, "Meteorites," chap. v.

[3] *Meteoriten-kunde*, Heft I, p. 327.

argues against such an origin of their substance, and further, Fouqué and Lévy produced by cooling from fusion, mineral aggregates as closely resembling meteorites as those made by Meunier from vapors. Again, the crystalline structure of the minerals of meteorites perfectly resembles that of terrestrial minerals known to be produced by cooling from fusion.

Concerning statement 6: That the complete crystalline structure possessed by the great majority of iron meteorites indicates a lapse of time sufficient for a slow, uniform arrangement of the molecules of their mass, in other words a slow cooling, has rarely been doubted. Such a conclusion certainly accords with all terrestrial experience and observation. It has been suggested by Cohen,[1] however, that the crystalline structure expressed in iron meteorites by the Widmanstätten figures may be really a sort of skeleton growth, similar to that seen when needles of ice form over the surface of rapidly cooling water, and that hence the Widmanstätten figures may indicate a rapid crystallization. It is unfortunate that no attempt to reproduce Widmanstätten figures artificially in iron has ever yet succeeded, for if this could be done valuable evidence for judgment on this point could be secured.

Taking the evidence as it stands, however, and especially taking into consideration iron meteorites like that of La Caille, whose structural features show a complete parallelism throughout a large entire mass, the indications seem to me to point strongly to slow crystallization. Certainly analogies between the formation of crystals in iron and in water should be drawn with hesitation. Iron is far more viscous than water and movement in it would take place slowly. Further, the crystalline plates of meteoritic iron differ in composition, showing that time must have elapsed for separation of ingredients as has not taken place in the ice formed upon water.

Concerning statement 7: This opinion is based chiefly on the large quantity of glass found in most of the chondritic meteorites, which, it is to be noted, make up by far the larger

[1] *Meteoriten-kunde*, Heft I, p. 326.

quantity of known stony meteoritic matter. Glass is known to indicate rapid cooling. Further, the character of the chondri themselves is such as to lead many students of the subject, notably Brezina and Wadsworth, to believe that they are the result of rapid and arrested crystallization. The fact that chrysolite, the least fusible and therefore the earliest cooling mineral, forms the most chondri, lends support to this view. It must be confessed that the real origin of chondri is as yet very obscure and the theory above suggested is far from accounting for many of their peculiarities. Yet the facts above noted seem to me to argue more strongly in favor of a rapid cooling of the substance found in such meteorites than a slow one.

If the arguments in favor of the above statements seem sustained, then the conclusion to which they appear to me to point is the following: *Meteorites are portions of a disrupted mass of cosmic matter which had a spheroidal form, increased in density toward the center, and cooled from a liquid or semi-liquid to a solid state before disruption.*

The application of this hypothesis to the subject in hand may perhaps best be traced by applying it in a reverse order. Given a defined quantity of liquid or semi-liquid. It will take the form of a spheroid, since this is the only form known in which a liquid mass would maintain itself in space. Its materials would arrange themselves according to density. The iron, for example, would sink to the center, and the slag-like silicates rise to the surface, as they may daily be seen to do in a blast furnace, or as a centrifugal separator assorts substances according to density. The exterior of the sphere owing to contact with the cold of space would be cooled with comparative suddenness, giving the minerals of the surface a glassy, brittle character. The protected interior would cool more slowly, giving the molecules of the metallic center an opportunity to arrange themselves in an orderly, crystalline fashion. In time, however, the globe becomes solidified from center to circumference. During the process of solidification, and later, many processes of disruption and adjustment go on as the

result of strains of various kinds, record of which is to be found in the structure of meteorites. Fissures will be formed, into some of which pasty metallic matter will be forced from below, and which will, in its passage upward, enclose angular fragments of the siliceous crust. Other fissures occurring only in the siliceous portion of the globe will give rise to the formation of quantities of angular fragments, which will be cemented together again by pressure to form breccias. Such fissures would be comparatively large, and affect a considerable area of the globe. Other minor fissures would form in ramifying networks, which would be filled by adjacent substance penetrating in a more or less liquid form. Differential movements of solid portions, without the existence of fissures, would produce slickensided surfaces. Finally, the progressive disruption of the body occurs. To produce this, two or three forces may be appealed to. In the first place, there is the familiar fissuring from shrinking and contraction as the body passes from the liquid to the solid state. It is perfectly evident that a certain amount of this is taking place upon the earth.[1] Meunier suggests further, that in the moon we can see this process extended as much farther as the moon is more fully cooled than the earth, and he regards the well-known bright streaks of the moon as enormous fissures (*rainures*) showing a progressive disruption of its mass.[2] While few probably at the present day would accept this interpretation of the bright streaks of the moon, there are numerous other indications that the moon is considerably fissured. Meunier also points to the asteroids as an illustration of a dismembered heavenly body.

In the second place, strains corresponding to the tidal strains of the earth would produce a constant disruptive effect; and, in the third place, the recent investigation of Professor Chamberlin,[3] has shown how the fragmentation of a small body may take place by near approach to a large one.

Once the body is broken up, its fragments may be drawn out

[1] See CHAMBERLIN, "On a Possible Function," etc., JOUR. GEOL., Vol. IX, No. 5.

[2] *Cours de Géologie Comparée*, pp. 258 *et seq.* [3] *Op. cit.*

into the form of a somewhat attenuated swarm or cluster. The possibility of the subsequent capture of single portions of such a cluster by the earth can hardly be denied. The character of the portion captured, in respect to its structure, density, and composition, then, will depend on the position it occupied in the globe of which it formed a part.

That meteorites exist in such swarms in space seems very probable from a recent investigation of Högbom.[1] Plotting the known meteorite falls according to the days of the year, he has discovered undoubted and significant groupings. Thus of the nine known howardites, three fell during the first days of August, and three during the first half of December. The probabilities are stated to be several thousand to one against such an occurrence being a mere coincidence. Again, of the three known eukrites two fell June 13–15. The chances are said to be ninety to one that these had a common origin. There are numerous other groups brought out on the chart so made, which seem to point to the existence in space of meteorite clusters met on the same date by the earth in its annual revolution. The probabilities seem sufficiently in favor of the existence of such clusters to warrant placing some reliance in the constitution indicated for them. Thus with the group of August howardites previously mentioned are associated one siderite and three chondrites; with the December howardites, one siderite, one bustite, one chladnite, and a number of chondrites. The constitution indicated for these swarms resembles therefore, to a remarkable degree, that called for by the hypothesis here advocated, especially when it is remembered how exceedingly fragmentary must be evidence based on the few meteorites seen to fall. A similar constitution has been also exhibited at times in the substance of a single meteoric shower. A notable case is that of Estherville, which contained all gradations, from iron to stone meteorites.

Two or three other points of evidence may be noted as tending to show that, in such a globe as that assumed, the substances

[1] *Bull. Geol. Inst. of the University of Upsala*, Vol. V., Part 1.

were arranged in order of their densities and that it had at some time a hot interior and cold exterior.

The first is drawn from our knowledge of the crystallography of iron. According to modern metallographists, iron occurs in three allotropic modifications known as alpha, beta, and gamma irons. When heated to a temperature not higher than 700° C., iron remains in what is known as the alpha state; from 700 to 860° C. it assumes the beta state, and from 860° C. to the melting point, the gamma state. In cooling, from the melting point, for instance, the iron does not necessarily return through these modifications, but remains in the state which it assumed at the highest temperature.[1] Now gamma iron crystallizes in octahedrons, while alpha and beta iron crystallize in cubes. The majority of meteoritic iron is plainly octahedral in structure. It is hard to escape the conclusion, therefore, that it has been heated to a temperature at least as high as 860° C., and, further, that the cubic irons, some of which occur among meteorites, have been subjected to a somewhat lower degree of heat. The latter, it is true, must be cooled and reheated to a somewhat lower temperature than at first to have their structure accounted for on this theory. But this could quite reasonably occur, and their relative quantity is so small as to make them of minor importance.

A second corroborative fact is that the carbonaceous meteorites are of exceptionally low specific gravity. Now the carbonaceous meteorites are those which contain hydrocarbons which could not exist under any high degree of heat. Such meteorites could not have experienced any sensible heating subsequent at least to the formation of these hydrocarbons. But the low density of these meteorites would place them, according to the hypothesis, on the outer surface of the spheroid, where, after the first solidification from cooling, little further heating would be encountered.

A third corroborative fact is found in the existence of diamonds in the iron meteorite of Cañon Diablo, a meteorite

[1] F. Osmond, *The Metallographist*, July, 1900.

which exists in quantity amounting to several tons. Such diamonds have been produced by Moissan by heating to a high temperature iron saturated with carbon and allowing it to cool under pressure. This is exactly the process through which the substance of an iron meteorite would pass if formed according to the above hypothesis. The other meteorite known to contain diamonds, Nowo-Urej, is also one which would have formed not far from the metallic center of such a globe, as it contains large metallic veins and by some is classed among the iron-stone meteorites.

The hypothesis outlined above may ask the special attention of the geologist, on account of the suggestions it may offer regarding the history of the earth. If it be true that meteorites are fragments of a broken-up globe, it is not unlikely that they show to us, to some extent, the constitution of our own globe. Uniformity of cosmic matter has been indicated by all studies of meteorites, as well as by all spectroscopic inquiries into the chemistry of space. Uniformity of cosmic history seems therefore probable also.

I have shown in the studies previously referred to that meteorites chiefly differ in composition from the crustal terrestrial rocks with which we are familiar in having an excess of iron, nickel, and magnesium, and in being practically without free silica, oxygen, and water. Assuming that the earth, however, has passed through a history like that of the globe above hypothesized, the absence of iron, nickel, and magnesium[1] from its crust is explained by the conclusion that they have been carried within its interior by their density. They are therefore removed from our observation, except as occasional outflows such as that known in Greenland bring them to view. It is well known that the density of the earth as a whole requires that its interior contain matter of higher specific gravity than that with which we are familiar upon its crust, and it has often been suggested that

[1] Magnesium is here referred to not as the element, which is relatively light, but as the essential constituent of chrysolite, which is of high specific gravity and forms some of the heaviest terrestrial eruptive rocks.

this matter may be iron and other metals. The alternative supposition is that the matter of the interior may be like that of the crust but has become denser through condensation and pressure.

The free silica of the earth's crust is readily accounted for if we remember that the rocks of the earth's crust have been *worked over*, while in meteorites they are seen in their primitive condition. When silicates are exposed to the action of carbonic acid for any length of time the bases change to carbonates and silica is set free.[1] It seems reasonable to suppose that the vast amount of calcium and magnesium now held as limestone was originally in the form of silicates. If the carbonic acid of the limestones should be withdrawn to the atmosphere, and their bases combine with the excess of silica of the crust, rocks as basic as those of meteorites would probably be formed.

Similarly, the lack of oxygen in meteorites may be only relative, and because much of the matter of which they are composed was in the interior, deep-seated and protected from gaseous action. The superficial, lighter siliceous portions of meteorites are found to be oxidized. It is reasonable to believe the earth's substance is not oxidized except for its superficial crust. It may be urged in support of the view that oxygen could not have been present where meteorites were formed that little or no oxygen is found among the free gases obtained from meteorites. But rocks do not seem to have the power of absorbing and holding oxygen as they do other gases. Terrestrial rocks do not contain it, although they hold hydrogen, carbon dioxide, and carbon monoxide in large quantities.[2] Yet there is no lack of oxygen in the earth's atmosphere.

The absence of water from meteorites is an important gap in the parallelism of constitution of meteorites with that of the earth. In the gases hydrogen and oxygen, which it has been shown meteorites possess, a cosmic body has the elements necessary for the formation of water. Conditions of nascence, or possibly of electricity, might exist in a body the size of the

[1] This fact is more fully stated by SIR JOHN MURRAY, *Proc. Roy. Soc. of Edinburgh, 1890–1*, p. 229.

[2] See *Studies*, JOUR. GEOL., Vol. IX, p. 402.

earth, which would lead to the formation of water from these gases, which might not prevail upon a body of smaller size. The chief reason, however, for the absence of water from meteorites seems to be the fact that the size of the meteorite spheroid was probably not sufficient to enable it to hold a quantity of the free gases competent to the formation of water or even to retain water vapor if it was once formed. The spheroid was probably as destitute of an atmosphere as the moon.

I am well aware that an origin of meteorites from a shattered globe has been suggested before. Boisse was perhaps the first to do this,[1] but the idea was especially elaborated by Meunier,[2] who reconstructed from the various types of meteorites a hypothetical globe in which these types were arranged largely in accordance with their density. But the hypotheses of these authors were based purely on considerations of density, it being arbitrarily assumed that in a cosmic body substances *would* arrange themselves according to density.

It was when a study of the structural characters of meteorites showed me that the substances *had* apparently arranged themselves in the order of their density, and exhibited corresponding differences of structure, that I was led to form the above hypothesis; and it is perhaps worth remarking that I reached this conclusion before I had seen Meunier's papers on the subject.

It is not likely that the globes or spheroids, such as have been here hypothesized, were of large size. In the solar system, for example, there is no indication that the total disruption of a body anything like in size to a planet has ever taken place. Such an occurrence would produce effects more catastrophic in their nature than could be referred to matter so small in relative quantity as that which has within human experience reached the earth in the form of meteorites. Such globes would, perhaps, in their entirety, never come within human observation. But that there exists in space a vast quantity of fragmental matter beside that visible to us as stars, nebulæ, and the bodies of the solar system, there can be little doubt.

OLIVER C. FARRINGTON.

[1] *Memoires de la Société des lettres, sciences et arts de l'Aveyron*, Vol. VII, p. 168.

[2] *Cours de Géologie Comparée.*

EDITORIAL

WITH this number we present to the readers of the JOURNAL two able articles on geologic classification and nomenclature. It is expected that these will be followed by others representing different points of view. In the opening numbers of the next volume we hope to offer a series of very carefully matured articles on the classification and nomenclature of minerals and rocks, by some of our foremost petrographers. It is hoped that these discussions will receive the thoughtful consideration of progressive geologists and petrographers. The importance of revising our present systems of classification and nomenclature, if systems they may be called, is equaled only by the importance of thorough preliminary scrutiny of the proposed substitutes, lest we impose on ourselves new systems scarcely less infelicitous than the old. A critical and deliberate circumspection, attended by full discussion, may well be followed by the adoption of the improved systems by those who have become convinced of their merits, if full liberty to follow the old practice is unreservedly accorded to the unconvinced and to the constitutionally conservative. It is doubtful whether we should try to force new systems into usage by legislative processes, but concerted adoption by those who have the courage of their convictions will go far towards securing the desired end.

T. C. C.

Reviews.

Zinc and Lead Region of North Arkansas. By John C. Branner (Arkansas Geological Survey, Annual Report 1892, 396 pp., Little Rock, 1901.)

The lead and zinc deposits of the Ozark region have received attention from the geological surveys of Arkansas, Missouri, Kansas, and the federal government. The United States Geological Survey and the University Geological Survey of Kansas will shortly have out reports on the subject. Missouri, through her geological survey, has already published an exhaustive account of the deposits in two large volumes, by Mr. Arthur Winslow. After delays of nearly ten years, Arkansas has at last seen fit to make appropriations for the publication of the report on the zinc and lead deposits of the north part of the state. It is by the former state geologist, Dr. J. C. Branner.

The publication of Dr. Branner's report has long been looked forward to by all interested in the subject of lead and zinc. In many respects it is the most welcome contribution to our knowledge of the geology of the Ozark region that has yet been made.

Preliminary to the consideration of the ores is a short description of the surface relief of the region, illustrated by an excellent photographic reproduction of Branner's Relief Model of Arkansas. The zinc and lead deposits described are located chiefly north of the Arkansas river. "The region here included under the name of Ozark plateau embraces nearly all of that part of the Ozark mountains within the state of Arkansas. It includes almost the entire region between the Arkansas river and the Missouri line, and between the St. Louis, Iron Mountain & Southern railway and the Indian Territory line. The Ozark region in Arkansas is made up of three plateaus that rise like ragged-edged steps one above another, each with a few outliers standing out upon the next step below."

In order of their importance, the zinc ores of northern Arkansas are sphalerite, smithsonite and calamine, besides several other minerals of zinc which do not occur in sufficient quantities to entitle them to be looked upon as ores.

The zinc ores are regarded as having been deposited by underground waters. Emphasis is laid on their accumulation along synclinal troughs and water-way breccias. "The details of the theory of the accumulation of the Arkansas ores along synclines and other water-ways were first suggested by field observations made in this region in 1889, and the whole theory has been much strengthened by subsequent work."

According to their genetic relations there are three kinds of sulphide ores: (*a*) the bedded deposits, which are contemporaneous with the rocks in which they occur; (*b*) the veins and other fracture deposits in which the ores are of later age than the accompanying beds, and (*c*) the breccia deposits not formed on fractures, but likewise of later age than the accompanying beds. In addition to the sulphide ores there are carbonate and silicate ores, derived by alteration from the sulphides and forming genetically a fourth class.

Regarding the origin of the bedded deposits, it is stated that they "have originated for the most part where we now find them." The cherts are made of silica of organic origin, that is, they were deposited over the sea bottom as silicious skeletons of diatoms or other microscopic remains of plants or animals. The zinc came from the adjacent land areas of the period in which these beds were laid down. Upon entering the sea the zinc-bearing waters had their zinc contents precipitated in the form of sphalerite or zinc sulphide by the organic matter that contributed the silica of the chert beds. The zinc crystallized out while these silicious sediments were yet soft and yielding. In time the sediments hardened and formed the firm, flinty rocks and pressed closely about the zinc blende crystals.

"The crystals of zinc blende, however, were not originally as large as we now find them in the disseminated ores, even where these crystals are no larger than a pin head. They were at first even microscopic, but, as Ostwald has pointed out, there is a tendency in such cases for the small crystals to pass into solution and to recrystallize upon the larger ones which grew at the expense of the small ones. In the bedded deposits this took place before the enclosing sediments were hardened."

The vein deposits are those occupying the spaces left by fractures in the strata. The ores are confined to the fractured zone and to its immediate walls. When the ore is found in the walls it seldom penetrates them to any considerable depth, but is confined to small

fractures that seem to be parts of the great fissures. In appearance the fissure ores are not different from the bedded deposits. But they are stated to have a very different origin. The ores of this class have all been brought into their present position by solution, probably from the Ordovician bedded deposits.

The question of the origin of the breccia ores "has been one of the most puzzling problems encountered in the zinc regions. The only theory for these formations that seems tenable is that of the apparently irregular masses of breccia, that is, the breccias not upon fault and such like fractures, have been formed along ancient underground water-courses."

One of the most suggestive points brought out in this consideration of the zinc ores is the relation of synclines to the presence of ores. Dr. Branner says: "If the hypothetical history here assigned the north Arkansas zinc ores is thus far correct, we are forced to conclude that the geologic structure of the region is of the utmost importance in the determination of the present distribution of the ores. In an elevated region of approximately horizontal or very gently folded sediments, the waters falling upon the ground and soaking into the earth tend to seek the bottoms of the synclinal troughs. The process of ore accumulation in such a region would therefore tend to carry the ores into the synclines. The rocks of the zinc region, although not far from horizontal, are gently folded. Wherever folds have been exposed in the zinc mines the bottoms and sides of these folds have been found richer in zinc than the adjacent portions of the same beds. This is a rule to which I know but few exceptions. The inference seems to be warranted that the synclinal troughs should be located and examined for the richer zinc accumulations."

Of exceptional interest at this time are the notes on the faults of north Arkansas. For the first time in the consideration of the zinc region something tangible regarding these structures and their character is made available. The throw of the faults, though never very great, is sometimes four hundred feet or more. The character of the folds found in the vicinity of the faults is shown by numerous figures.

The illustrations are unusually good.

C. R. Keyes.

Texas Petroleum. By WILLIAM BATTLE PHILLIPS, Ph.D., Director. The University of Texas Mineral Survey Bulletin No 1; 102 pp., plates, maps. Austin, July, 1901.

THE University of Texas Mineral Survey, organized in May, 1901, with Dr. William B. Phillips of the university as director, establishes a new record for expeditious work in official geologic investigation by the timely appearance of this volume on a subject which is attracting much attention within the state and without.

An historical account of the development of the Texas oil fields is followed by a chapter on the nature and origin of petroleum, and other chapters on the oil and gas-bearing formations and the utilization of Texas oils.

The Paleozoic formations are not known to hold oil or gas in commercial quantities. The Cretaceous formation, more specifically the Corsicana field, has furnished practically all of the oil which has been produced until the current year. This field has a well-defined extent of from two to three miles in width by six and one-half miles in length in a northeasterly direction. The oil is reached at a depth of 1,050 feet in a soft, gray, foraminiferal shale. In July, 1901, there were 603 producing wells, with an average daily output of about 3,000 barrels of oil worth 70 cents per barrel. The production of oil in Texas for 1899 was 669,013 barrels, while that for 1900 was 836,039 barrels, almost all coming from this field. The Corsicana refinery has a capacity of 1,500 barrels of crude oil daily. Half the output consists of gasoline and kerosene, the residuum being marketed as fuel.

In the Tertiary, the Nacogdoches field was the first to be discovered, dating from 1867. The oil is found in Eocene strata at depths of 70 to 150 feet, and is a heavy lubricating oil with a high boiling point and non-gumming qualities. No oil has been produced in this region since the early part of 1900.

The Beaumont field has been the center of attraction since January 10, 1901, when the famous Lucas "gusher" was brought in. In July, 1901, there were fourteen producing wells all within an area 1,000 by 2,000 feet on Spindle Top Heights, a low ridge lying about four miles south of Beaumont. The ridge is about one mile wide and two miles long in a northeasterly direction and reaches a maximum elevation of 30 feet above the surrounding prairie. Wells outside the proven area are dry. It is presumed that the ridge marks an anticline, though

the structure is not yet known certainly. Concerning the fabulous production of the gushers, no definite figures can yet be given, but the production is unquestionably large. Pipe lines connect the field with tide water at Sabine Pass and Port Arthur where refineries are in process of construction. In quality the oil is a heavy fuel oil, the price of which, in July, 1901, varied from 20 to 40 cents per barrel.

In connection with the origin of the oil, an investigation was made of the so-called "oil ponds," certain quiet spots in the Gulf near Sabine Pass and popularly supposed to be caused by oil escaping from submarine springs. The areas were found to be over extensive beds of black ooze. The examination of samples of this ooze disclosed the presence of sulphur and of diatoms containing oil globules, but of no free oil except such as manifestly came down from the overflow of the Beaumont wells. Sulphur deposits occur over the Beaumont oil horizon. The possible analogy of the present conditions to the conditions prevailing when the Beaumont oil-bearing formation was deposited is suggested as well as the possible connection of diatoms with the oil production.

The report is well printed and illustrated with a number of photographs of characteristic scenes in the different fields, including several of the "gushers" in action, and is in all respects a worthy inauguration of the new survey.

C. E. S.

Lessons in Physical Geography. By CHARLES R. DRYER. American Book Co.: New York, Cincinnati, and Chicago, 1901.

This text-book of high-school grade covers the field of physical geography from the modern standpoint. It has several characteristics for which it deserves recognition as more than a mere variation of what has already been accomplished in other books. It is, first of all, a very concrete presentation of the physiographic principles which have recently come into prominence. Thirty-four pages are given to three typical river systems, the Mississippi, the Colorado, and the St. Lawrence, and thirteen pages to the drift sheet of North America, beside the general treatment of glaciers. The chapters which are devoted to more general subjects also abound in descriptive examples and pictorial illustrations. In the second place, the book has a large number of illustrations which are new to text-books; many of these are drawn from Indiana and neighboring states and will be welcome

to teachers as showing that the modern science of physiography does not rest on a few classical examples. The book leaves the very wholesome impression that the United States abounds in valuable illustrations which are yet unknown to text-book literature, the bringing forward of which depends largely upon teachers who are working in their vicinity, just as Mr. Dryer has sought out those of his own state. The arrangement of the book is good for those who may wish to follow the author's own order and convenient for those who do not. The suggestions on method, both in the "Realistic Exercises" and in the appendix, are helpful. The teacher is introduced to many of the valuable materials which are now available for this study. A good bibliography is given. The author is plainly in touch with the most recent work in his science. A few statements or suggestions in geology do not take into account some of the recent work. A sentence on p. 48, despite previous cautious statements, implies the belief that isostacy alone may support the earth's broad plateaus. On the same page the wrinkling of the earth's crust is ascribed solely to cooling of the interior. A faulty impression of slate would be left by the mention on p. 32. Under "Causes of Glacial Motion," three theories are mentioned: plastic flow, regelation, and alternate melting and freezing. Processes which in recent studies have become more prominent than these are not mentioned. The too general and perhaps misleading contrast between the "older drift" and the "newer drift" are not due to any lack of information on the author's part, whose familiarity with the complexity of drift problems is shown both in this and other writings. An unfortunate expression on p. 135 would leave the impression that the Great Basin as a whole is actually a *basin* with a rim. The mention of "subordinate basins" serves to emphasize this error. Small shortcomings like those mentioned here are but rare exceptions in this very good text-book. In its characteristic qualities the book not only meets the general demands of good science and good teaching, but is well adapted to the particular needs of the present time.

N. M. F.

Some Notes Regarding Vaerdal; The Great Landslip. Dr. Hans Reusch. *Norges geologiske Undersögelse;* Aarbog for 1900.

This complete and well illustrated note, which Dr. Reusch has summarized in English, recounts a very remarkable landslip. The

level surface into which the river Vaerdal has cut a steep-sided valley is an upland of stratified marine clays, deposited during a submergence of the Norway coast since the Glacial Period. Within these clays was a great mass of "quick clay" not constituting a definite stratum but existing, probably, in more or less definite lenticular masses. A small side stream, the Follo, had cut a short gorge into the quick clays, giving the latter an exit to the main valley. On the night of the 19th of May, 1893, a volume of this semi-fluid clay, estimated at 55 million cubic meters, escaped into the larger valley, inundating it to the extent of eight and one half square kilometers. The collapse occupied one half hour and the advancing front of the mud traveled five or six kilometers in three quarters of an hour. Some of the inhabitants were rescued from the roof of their house after sailing three and a half miles on the river of mud. Over a part of the area the upper layer of clay was firm, and, with the overlying turf, constituted a crust sufficiently strong to remain intact while the quick clay flowed out from beneath. Parts of fields bearing trees were thus dropped vertically downward, leaving the trees standing erect at the lower level. The vertical distance through which the surface fell is not given, but the pictures represent it as many meters and the sides of the pit as quite sheer in many places. The author gives a note, also, on a similar but smaller landslip which occurred on the 16th of August of the same year in the valley of the small stream Graaelven. The finely banded marine clays concerned in this slip are made the basis of a time estimate. Their thickness is taken at fifty meters, and they consist of alternating dark and light layers. On the supposition that one dark layer and an adjacent light layer were deposited in one year, the time consumed in their deposition is estimated at 4,000 years. The proportion of post-glacial time which this represents is not estimated.

N. M. F.

Geological Map of West Virginia. Second edition. I. C. White, State Geologist. Published by West Virginia Geological Survey, Morgantown, W. Va.

The Geological Map of West Virginia, first published in 1899, has recently been revised and new features added. The map shows in separate colors the three great coal formations of West Virginia, viz., the New River or Pocahontas, the lowest; the Allegheny-Kanawha

series in the middle; and the Monongahela or Pittsburg (Connellsville) at the top. Two features not shown on the original map have been added in this edition, viz., the prominent anticlinal lines, and the locations and names of every coal mine in the state shipping coal by rail or river, up to July 15, 1901, the approximate locations of the mines being indicated by numbered black dots, and the corresponding names and numbers printed on the margin of the map by counties. The map shows also oil and gas developments of the state, and should prove of much use to those interested in these subjects. Copies may be purchased (50 cents) from the West Virginia Geological Survey, Box 448, Morgantown, W. Va.

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THE

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THE FOYAITE-IJOLITE SERIES OF MAGNET COVE: A CHEMICAL STUDY IN DIFFERENTIATION. II.[1]

DISCUSSION.

In the table below are given the chief molecular ratios of those analyses of the Magnet Cove rocks which I am led to believe are the most reliable and representative. There are also

	I	II	III	IV	V	VI	VII	VIII
SiO_2	38.39	38.93	41.75	44.40	49.70	53.09	60.13	60.20
TiO_2	4.54	1.62	0.58	1.53	1.33	0.11	1.15	0.14
Al_2O_3	7.05	15.41	17.04	19.95	18.45	21.16	20.03	20.40
(FeO)	14.33	8.83	9.04	7.41	7.37	3.74	3.45	3.44
MgO	11.58	5.57	4.71	1.75	2.32	0.32	0.76	1.04
CaO	19.01	16.49	14.57	8.49	7.91	3.30	0.87	2.00
Na_2O	0.74	5.27	6.17	6.50	5.33	6.86	6.30	6.30
K_2O	0.75	1.78	3.98	8.14	4.95	8.42	5.97	6.07
Molecular Ratio								
SiO_2	.640	.649	.696	.740	.828	.885	1.002	1.003
TiO_2	.055	.019	.007	.018	.015	.001	.014	.002
Al_2O_3	.069	.151	.167	.196	.181	.207	.196	.200
(FeO)	.199	.123	.127	.082	.102	.052	.048	.048
MgO	.290	.139	.118	.044	.058	.008	.019	.026
CaO	.339	.294	.260	.152	.141	.059	.015	.036
Na_2O	.012	.085	.098	.105	.086	.117	.100	.102
K_2O	.008	.019	.042	.087	.053	.090	.061	.065
$\frac{Na_2O}{K_2O}$	1.50	5.00	2.33	1.21	1.62	1.30	1.64	1.57
Specific Gravity	3.407	2.769	3.084	2.770		2.599	2.557	2.642

I. Jacupirangite.
II. Biotite Ijolite.
III. Ijolite.
VI. Arkite.
V. Covite.
VI. Foyaite, Diamond Jo.
VII. Pulaskite, Braddock's quarry.
VIII. Pulaskite, Type, Fourche Mt.

[1] Continued from p. 622.

inserted the figures for my two analyses of the Fourche Mountain rocks, which, although somewhat distant from Magnet Cove, undoubtedly belong to the same general regional magma. To render the diagrams less complicated the iron oxides are calculated together as (FeO).

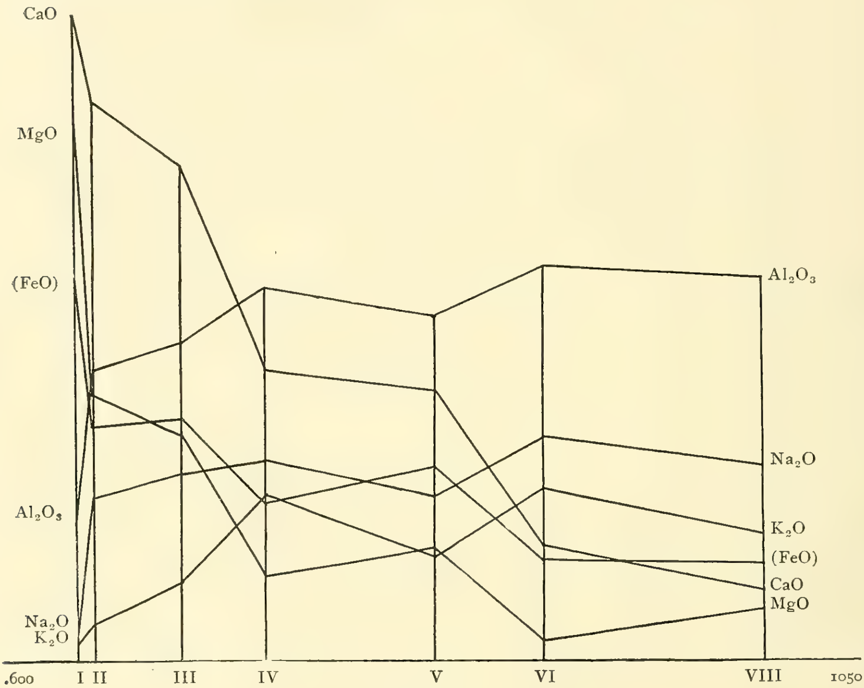

DIAGRAM I.

It has already been explained that at Magnet Cove the arrangement of rocks from center to periphery is regularly serial, from basic to intermediate, *i. e.*, from II to VI. If, therefore, the analyses are plotted according to Iddings's method, using the silica values for the abscissae, the diagram will represent in a general way the variation of this particular magma in space. This was done in my former paper[1] for the earlier analyses, and the results of the present investigation are shown in Diagram 1.

[1] H. S. WASHINGTON, *op. cit.*, p. 404.

Comparison of the two shows that the curves, or rather zigzags, are much alike even though the analyses of (and consequently the abscissal positions of the figures for) arkite are different in the two. At the same time the new diagram is markedly more broken, and varies less regularly and continuously than the former. The regularly serial character of the first is thus apparently diminished, and what it was thought would be an excellent example of regular differentiation seems to turn out rather the contrary.

But, as Pirsson justly remarks, the use of SiO_2 for the abscissae is arbitrary, and, since this is one of the most important rock ingredients, its variation should also be shown in a manner directly comparable with those of the other oxides.

It would seem to be undeniable that this is a legitimate, indeed a most logical, method if the differentiated mass has not suffered disturbance and if circumstances permit the determination of the correct distances of the various differentiates from the center, since the diagram then represents, not only the compositions of the various phases, but their actual relations in space, both as to direction and as to relative position.

It often happens, as apparently at Magnet Cove, that the successive differentiation products are sharply separated from each other, transition forms being either lacking or very small in amount as compared with the main types. To correspond then with the actual state of affairs, the diagram should consist of steps, *i. e.*, horizontal lines of a length equal to the breadth of each zone, at the respective ordinal positions for each oxide.

Since, however, the analyses may be assumed to represent the average composition of each differentiation product, and we desire to study the course and the laws of differentiation, it is legitimate to represent the position of each constituent by a point, and the lines connecting these will therefore express the course of the differentiation of the mass of magma, even though, as an actual matter of fact, all the possible gradations represented by the curves may not be present. Such a procedure is quite in accordance with the general practice in chemical and

physical research, and this point is mentioned only because such methods have, as yet, found little application in petrography.

In order to construct the curves two important field data are required; the position of the center of the mass or area, and the relative distances from this of the various types analyzed.

By center is meant that of the innermost petrographic zone or core, not necessarily the geometrical center of the mass, as this petrographic center may be conceivably geometrically eccentric. Since, in many cases, as here, we have only one section, a horizontal one, this point is not necessarily the center of the mass, but rather its epicenter, to use the seismological term.

Since the area of Magnet Cove forms a fairly regular ellipse with axes of about 5 and 3 kilometers, the center of the igneous area is easily determined. Its position is marked approximately by the Baptist church,[1] which lies in the small central exposure of biotite-ijolite. Inasmuch as we do not know whether the plane of the present exposed area cuts the mass centrally or above the center, we cannot tell whether the central point of this is the true center of differentiation or not. It is probably not so. But as far as the types exposed are concerned this is of little moment, as their mutual relations would remain the same, or approximately so, in any case.

Having determined the center the next point is to determine the distances of the various types from this. It is obvious that for the proper plotting of the curves, and hence the study of the course of differentiation, this is of great importance, since the points which determine the various curves will be shifted in one direction or another according to the distances selected. This would alter very materially the slope of the curves, and even their character or shape, as by the shifting of the abscissal positions a straight line will become a curve, or a simple curve of the second degree may assume the form of an inflexed one of the third.

At Magnet Cove we cannot determine the abscissal positions by simply measuring the distances from the center to the particular spots where the analyzed specimens were collected,

[1] *Cf.* the maps in papers already cited.

because, owing to the elliptical shape of the area, a specimen (*e. g.*, covite) from near the end of the major axis may be at an actually greater distance from the center than one (*e. g.*, foyaite) from the end of the minor axis, though genetically inside the latter.

It would, of course be best to have several analyses of each type from different parts of the zones, both radially and circularly, so as to get the mean composition of each. But as that involves the making of very many analyses, we must be content at present with selecting what seem to be representative specimens, and assume that their analyses correspond to the average composition of each type.

Assuming this, two courses are open to us. We can either measure the distances from the center along a radial line on which all occur, or average the distances of the various occurrences of each type. The latter has been the process adopted here, since it seemed more likely to eliminate errors due to local conditions.

For each type measurements were made on Williams's map in many directions from the Baptist church to the middle point of each zone exposed, and the mean of these taken in each case. On the diagrams the abscissal positions of III, IV, V and VI, from the origin at II represent these relatively, as it is not necessary that the diagrams be of the same scale as the map. The position of the foyaite (VI) is not fixed as accurately as those of the others, since, being at the periphery, it is in great part overlaid by the surrounding shales. Small outcrops outside the main area, however, allow a rough estimate of its average distance, though it undoubtedly extends farther away from the exposed area than the few outcrops indicate.

In my former paper I assumed that the petrographic center of the area was in the "magnetite bed," and that this was the result of the decomposition of underlying jacupirangite. As, however, this is quite uncertain, it seems best for the purpose in view to disregard this area. For the present then the analysis (and the diagram position) of the jacupirangite may be neg-

lected. The same is true of the pulaskite analyses, these rocks lying quite outside the Magnet Cove area. All these rocks will be discussed subsequently.

We thus obtain the result shown in Diagram 2, where the points are connected by straight lines. In this, and the following, the vertical scale for SiO_2 begins .400 lower than the others, so as to condense the diagram and at the same time preserve

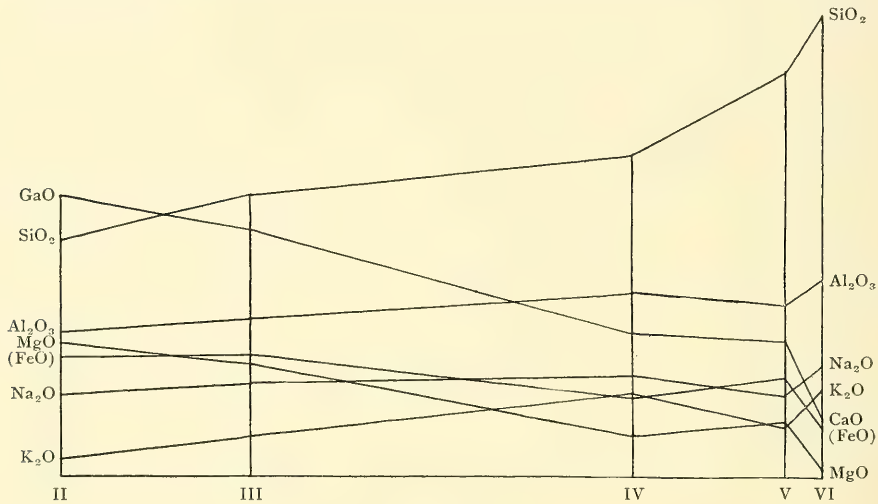

DIAGRAM 2.

the relative forms of all the curves (given later), and not flatten that of silica, as would be done if a smaller vertical scale were used for this than for the other constituents.

When Diagram 2 is examined it is clear that, with the exception of the values for covite (V), all the points of the respective oxides lie along very smooth curves. For convenience in further discussion the curves formed by the figures for II, III, IV and VI are plotted separately in Diagram 3. The values for V (covite) are entirely omitted from this, and the position and relationships of this rock will be discussed later on. The curves marked *F* and *M* will also be explained presently. All the curves, it may be mentioned, were drawn with a spline, so that the personal equation is eliminated as far as possible.

Within the limits from II to VI the curves are simple, that of SiO_2 alone showing inflexion about at the center of the diagram, rising sharply toward the right (acid end) and falling gently toward the left (basic end). Most of the curves are quite flat, especially those of Al_2O_3, Na_2O and K_2O, which approximate straight lines. At the same time they are all distinctly

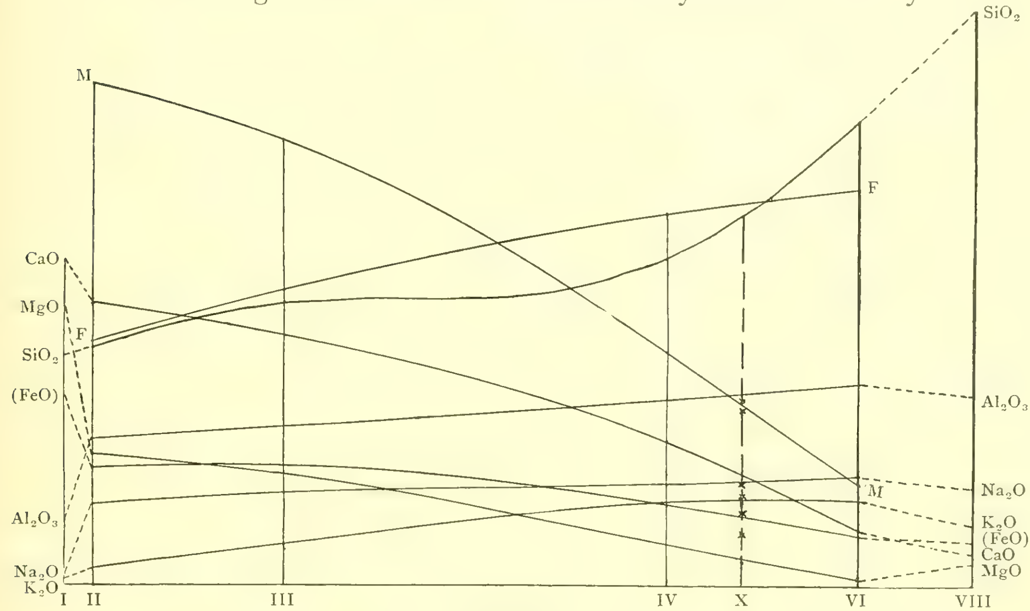

DIAGRAM 3.

curves and not strictly linear.[1] It will be remembered that Pirsson[2] says that all of the lines of his diagram should probably be drawn as very flat curves (much flatter than these), and these observations are in accordance with the conclusion of Harker,[3] that strictly linear series of rocks are of rare occurrence.

With the exception of SiO_2, which is inflexed and that of

[1] This is best seen in the large-scale drawing from which the diagram is reproduced.

[2] L. V. PIRSSON, *op. cit.*, p. 571.

[3] A. HARKER, JOUR. GEOL., Vol. VIII, p. 392, 1900.

Al_2O_3, which is almost a straight line but slightly convex,[1] all the curves are concave[1] (toward the bottom).

The curves divide themselves naturally into two groups, according to general direction. Those of SiO_2, Al_2O_3, Na_2O and K_2O ascend toward the right (the periphery), the three last almost arithmetically. It will be noticed that the K_2O curve ascends more rapidly than that of Na_2O to a point a little to the right of IV, when it drops a trifle more rapidly. This is expressed in the series of the ratios of these two oxides, already given in Table I. The second group is that of (FeO), MgO and CaO, which descend toward the right, and at a greater rate than those of the other group rise, SiO_2 excepted.

It may be noted, by the way, that if TiO_2 be plotted with SiO_2, the curve of the sums of the two becomes rather more flat (especially about IV), and the inflexion at the left is almost overcome. For facilitating this observation I have put the molecular ratios of TiO_2 next to those of SiO_2 in the table, though it would complicate the diagram unnecessarily to put in this joint curve. This seems to confirm the general belief that TiO_2 plays the part of an acid radical, like SiO_2, in rock magmas.

The general results can be concisely shown by plotting the sums respectively of the "ascending" and the "descending" oxides, except silica. We then get the two curves *F* (that of Al_2O_3, Na_2O, K_2O) and *M* (FeO, MgO, CaO), on the line of which all the determining points fall very exactly. They are both decidedly concave, *F* ascending and *M* descending, and their smoothness and regularity are very striking.

These results are in strong harmony with those of Pirsson, and the general characters of the curves in each diagram are very similar, though there are some differences in detail. Thus all his curves are much flatter, the SiO_2 does not show signs of inflexion, and the Al_2O_3 is concave and K_2O convex, while in mine these two are reversed. But these are small matters, possibly due to the abscissal distances at Yogo Peak not being as

[1] The terms convex and concave will be understood as referring always to the *X* axis, the bottom of the diagram.

easily ascertainable as at Magnet Cove. The general conformity of the two is very good evidence to show that, if plotted according to their spacial (*i. e.*, genetic) relations in the mass, the analysis of the components of an igneous complex will furnish regular curve. This fact is almost proof positive of the view that the variation of rocks is due to differentiation of some sort.

Whether this differentiation is always as is now believed, viz., that the oxides of Al, Na and K tend to segregate in one direction, while those of Fe, Mg and Ca segregate in another, as well as the process by which these changes are brought about, are separate questions, which further investigation must settle. It may be that the general course indicated by the diagrams of Pirsson and myself are typical of all rock differentiation, or it may be that with magmas of different character the course of differentiation may be radically different, and that the same oxides do not always tend to go together.

At any rate, it may be confidently expected that where a mass of magma has been differentiated *in situ* and is of approximately regular shape, has not been subjected to secondary disturbing conditions, and the exposures sufficient, we can express the relations of the differentiation products and the course of differentiation mathematically, as has been done in these two instances. Of course, for this purpose, it is absolutely essential that the analyzed specimens be representative, and that the analyses be complete and accurate. Otherwise the curves will be misleading or else uneven zig-zags, only rough approximations to the truth, and possibly not even that. There must also be present at least three differentiates, as otherwise only straight lines connecting the two can be drawn.

The fact that the SiO_2 curve is the only one which is inflexed, and that it runs very sharply up toward the acid end, leads to some interesting conclusions. Since, toward the acid end, the curves of (FeO), MgO and CaO drop much more rapidly than those of Al_2O_3, Na_2O and K_2O, it is evident that at a short distance to the right (in other words with a slight increase in

silica), they will practically disappear if the differentiation continues as indicated by the body of the diagram. Further differentiation in this direction then would lead to the production of a purely feldspathic or feldspathoidal rock. If continued still further quartz (free silica) would appear and the rock become aplitic in character. Finally, since the silica is increasing at a rapid geometrical rate, while the other constituents are dropping, the extreme result of differentiation in this direction would be pure quartz.

This inference is obviously in line with the experiments of Barus and Iddings[1] which indicated that in igneous magmas SiO_2 plays the rôle of electrolytic solvent, analogous to that of H_2O in aqueous solutions. This result is also in harmony with the experiments and conclusions of Lagorio[2] and Morozewicz,[3] who come to the conclusion that the predominant magmatic solvent is composed of silica and alkalis, and that it has the power of dissolving large amounts of alumina. The results obtained above would indicate that alumina itself is an essential constituent of the solvent, and it would also seem that there need be no stoichiometrical ratio between the four constituents. As has been indicated above, however, it will not do to push conclusions too far from such meager data, and it is by no means necessary to infer that a rock solvent of this character is the only possible one. But it will be as well to defer all discussion of these topics until more complete data are available.

The comparative rarity of occurrences of purely or very highly siliceous igneous rocks may presumably be ascribed to the fact that long before this phase of differentiation has been reached, the mass will, in most cases, have become solid (owing to the high melting point and great viscosity of such mixtures), and hence incapable of further change in this way.

It is of interest to note in this connection that a specimen of "aplite" has been collected by Dr. Weed, and is now in the

[1] Barus and Iddings, *Am. Jour. Sci.*, Vol. XLIV, p. 248, 1892.

[2] Lagorio, *Min. Pet. Mitth.*, Vol. VIII, p. 508, 1887.

[3] Morozewicz, *Min. Pet. Mitth.*, Vol. XVIII, p. 235, 1899.

United States Geological Survey Reference Collection (No. 813). It is of a small dike, about one and a quarter inches wide, cutting the shale near Neusch's gulley, which it has metamorphosed. I am indebted to Dr. Ransome for the examination and description of this specimen which he sent at my request. "Under the microscope, the dikelet is seen to consist almost wholly of cloudy alkali-feldspar, with no quartz or nephelite, and a little biotite. With high power, the feldspar (between crossed nicols) all shows the fine shadowy striping indicative of a soda-bearing feldspar." Two garnets also occur at the borders of the dike. The occurrence of this aplite dike is clearly corroborative of the view of the course of differentiation which has been just expressed, and it is probable that further search would reveal others which have heretofore escaped notice.

Turning to the other end of the diagram, there is good ground for the belief that there must be inflexion upwards of one or more of the curves beyond II to the left. If the curves are extrapolated to the left, at a distance, let us say, equal to that between II and III, the sum of the constituents reduced to precentages amounts to only 55.6.

It is obvious therefore, either that some other component of the magma than any of those plotted is greatly concentrated at the basic end, or else that the curves of one or more of the plotted constituents must run very sharply upward, thus causing inflexion.

In the former case a probable additional constituent would be P_2O_5, which would yield, with high CaO, MgO and (FeO), an apatite-rich pyroxenite like that of Ahvenvaara in Finland,[1] or with disappearance of SiO_2, an apatite-magnetite rock like that of Alnö.[2] If TiO_2 should be the constituent to assume extraordinary proportions toward the basic end, we would expect, with disappearance of SiO_2, titaniferous magnetites, or such rocks as the magnetite-perofskite rock of Brazil, described by Derby.[3]

[1] V. Hackman, *Bull. Com. Géol. Finl.*, No. XI, p. 36, 1900.

[2] *Cf.* Rosenbusch, *Elemente*, No. 3, p. 133, 1898.

[3] O. A. Derby, *Neues Jahrb.*, 1894, Vol. II, p. 297.

Such products are, however, very exceptional, and are only to be expected in cases of very complete differentiation. In general we would only look for sharp upward inflexions of the (FeO) and MgO curves, which would yield, with the slowly dropping silica and the high CaO, a pyroxenite rich in magnetite. This is just the character of the jacupirangite of Magnet Cove (I), and of those of Brazil and Alnö, and I have indicated its connection with the others accordingly by the dotted lines to the left.

Inasmuch as the specimens of this come from a small isolated mass outside the main area, its relations to the other types are uncertain, and its diagrammatic position has been given on the basis of its silica content. It seems to be probable that if, as is likely, such a rock is connected genetically with the others, its abscissal position should be considerably more to the left. As this rock is met with in the immediate vicinity of the main area, and is a theoretically possible differentiation product of the magma, it seems reasonable to assume that the section at Magnet Cove cuts the mass some distance above the center, and that below the biotite-ijolite is a core of jacupirangite, as previously supposed.

It is obvious from the theoretical discussion, as well as from observations here and at similar regions, that the relations toward the basic end are far more complex than at the acid end. This arises from the fact that the oxides involved here are capable of more numerous mineralogical combinations, and also because elements which are only present to a small extent in the body of the magma may here assume proportions of great importance. The fact that these extreme basic differentiation products are far more common than the purely siliceous ones may be ascribed to the greater fusibility of magmas of a basic character, and the consequent possibility of differentiation among them at temperatures when the more acid end of the series is solid.

In this connection attention may be called to the fact, analogous to the segregation of TiO_2 and P_2O_5 at Magnet Cove

and Brazil, that in large steel castings, such as those for modern artillery, etc., there is a very marked concentration of "impurities," as phosphorus and sulphur, toward the center of the mass.

As all the curves are so smooth and well defined, it seems highly probable that equations for them could be found and that their properties as such could be discussed. In this way we could get at an exact knowledge of the law of differentiation, in this particular case at least. It is a matter of regret that I am not mathematician enough to do this, but there are other applications of the data at hand which are capable of simple mathematical treatment.

Since the area of Magnet Cove is a fairly regular ellipse, and the zones of the various types are concentric about the center, by taking the average distance of each we practically reduce the ellipses to circles, the average distances being the radii.

Now, since II is at the center, if we suppose Diagram 3 to be revolved about the vertical line at II as an axis, it follows that the solids of revolution so generated by each of the curves (with the bounding lines at the sides and bottom), will represent the amount of each oxide in the original magma, and that their sum will represent the composition of the magma as a whole, before differentiation.

This is not strictly true, since we are ignorant of the exact shape and extent of the complex, but as a first approximation and an illustration of the method, it will be of interest to calculate the results which are obtained on this basis. As a matter of fact, the recent description of the Shonkin Sag laccolith by Weed and Pirsson[1] renders it extremely probable that the foyaite is present in far greater relative amount than the surface exposures indicate. This would necessitate a very considerable correction, but, as we have no means at present of estimating this, it will be as well to give the figures based solely on the field observations, leaving possible corrections for the future.

The process of calculating the various volumes is very simple in theory, but somewhat complicated and laborious in practice.

[1] WEED and PIRSSON, *Am. Jour. Sci.*, Vol. XII, p. 1, 1901.

As it is a somewhat new departure in petrography it may be of use to others to outline the method which I have employed. The curves shown in Diagram 3 were plotted on paper ruled in inches and tenths. The particular scale is simply a matter of convenience, and it is not necessary to reduce the percentages to 100, as we are dealing with relative amounts.

The formula employed is well known, being the second of Guldin's theorems, viz., the volume of the solid generated by the revolution of a closed curve or plane figure about an axis in its plane, but exterior to itself, is equal to the product of the area of the generating curve into the path described by the center of gravity of the revolving area.

$$V = 2\pi r A,$$

where V is the volume, r the distance from the axis to the center of gravity, and A the area of the plane figure.

The areas of the curve, *i. e.*, of the space embraced within the curve itself, and the limits of the diagram, are easily found, either by counting the squares, or by calculation of the area of the trapezoids formed by the respective chords and the limiting lines, and addition to these of the areas embraced between the chords and the curves.

The centers of gravity are found by dividing the trapezoids into two triangles, and finding their centers of gravity, when the center of gravity of the trapezoid will be at the intersection of the line connecting the centers of the two triangles and one connecting the middle points of the two parallel sides. In the case of the more curved lines a correction must be made for the area between the chord and the curve, but this will always be small. SiO_2 was regarded as composed of the large rectangle from .400 below the bottom of the diagram to .249, and the space between this upper boundary and the inflexed curve.

The resultant volumes, being based on the molecular ratios, have to be multiplied by the molecular weights of the respective oxides, in order to arrive at the percentage composition of the whole. In this way I obtained the following figures, which are given in full to illustrate the method.

	A	r	V	V × mol. wt.	Percentage	Mol. Ratio	
						Found.	Calc.
SiO_2	52.0 6.0	4. 5.4	1306.2 203.4	90576.0	47.24	.787	.787
Al_2O_3	14.0	4.25	375.7	38321.4	19.99	.196	.201
(FeO)	8.25	3.5	181.0	13032.0	6.80	.094	.074
MgO	5.9	2.9	107.4	4296.0	2.24	.056	.029
CaO	16.2	3.5	356.1	19941.6	10.40	.185	.117
Na_2O	8.1	4.1	208.6	12933.2	6.75	.109	.110
K_2O	8.8	4.75	134.2	12614.8	6.58	.070	.090
					100.00		

Of the Magnet Cove rocks this resembles most that of arkite (IV), especially as regards Al_2O_3, (FeO), MgO, and Na_2O, though it is distinctly higher in SiO_2 and CaO and lower in K_2O. Referring it to Diagram 3, its position established by means of SiO_2 is shown at *X*, and the points where this vertical is cut by the oxide curves are the "molecular ratios calc." of the table. The small crosses along the vertical indicate the positions of the various oxides as found. They can be identified by the values in the table.

It will be observed by reference to the diagram or to the last two columns of the table, that in the case of oxides whose curves are approximately straight lines, as Al_2O_3 and Na_2O, the found and calculated values coincide, while in the case of oxides yielding decided curves the value found is below that calculated.

This is in accordance with the demonstration of Harker[1] that if a series be linear the admixture of two or more members will produce a rock having the composition of a possible member of the series, while in a curvilinear series the mixture will not correspond to a possible member.

Another method for arriving at the composition of the magma as a whole would seem to be furnished by the determination of the mean point of each of the curves, thus giving the average composition. If the equations of the various curves were known, these could be calculated mathematically. But for practical purposes it can be done by determining, for each

[1] Harker, Jour. Geol., Vol. VIII, p, 394, 1900.

oxide, the ordinal value for each successive tenth of an inch, and taking the mean. The result of this process is given in II below, that given by the previous process being given in I.

	I	II
SiO_2........	47.24	45.44
Al_2O_3	19.99	19.06
(FeO).......	6.80	7.75
MgO........	2.24	3.31
CaO	10.40	11.81
Na_2O.......	6.75	6.37
K_2O........	6.58	6.26
	100.00	100.00

The two agree fairly well, and are of the same general character, though there are marked discrepancies, II being decidedly more basic in all respects than I. What may be the explanation of this, I am not mathematician enough to say. But the general agreement would indicate that one of the two, or their mean, cannot be far from the truth, *i. e.*, as near as the data at hand permit of approximation.

It is of interest to note that I have been unable to find the analysis of any rock which agrees at all closely with either of these two results. Those which are as high in alkalis being lower in bivalent oxides, while those which agree in this respect are lower in alkalis and alumina. Whether this indicates that there are serious sources of error in the method employed, or else that some undifferentiated magmas may possess chemical compositions not corresponding to those of rocks as yet known, is a question which cannot be decided here. It would seem as if there were nothing *a priori* contrary to the latter hypothesis.

In this connection Harker's[1] remark may be cited: "Given a series such that its diagram has markedly curved lines, the result of the admixture of two members may be something not only foreign to the series, but highly peculiar by comparison with igneous rocks in general." It is true that Harker was discussing the case of the mixture of two members of a series, but

[1] HARKER, *op. cit.*, p. 395.

differentiation and admixture (of two members of a series) may to a certain extent be regarded as inverse processes, so that the occurrence of a magma of this anomalous composition need not occasion surprise. Being rich in both of the generally antagonistic groups of oxides, it would be especially liable to differentiation. The general lability of the monzonitic magmas as regards the conditions controlling crystallization has been pointed out elsewhere.[1]

The general chemical composition can also be calculated by the relative volumes of the various phases, which has been the only method heretofore available. This would seem to be far more uncertain than the new method, which is based on the mathematical course of differentiation, since the ignorance of certain data may affect the result very seriously. Thus we cannot tell where the boundaries between two zones really fall, and (beneath the hornstone ridge especially) whether there may not be a zone of transitional material.

Assuming that the limits come half way between zones, and that they are of uniform thickness in all directions, we can easily

	Volumes	Weights
II	0.14	0.15
III	8.64	9.85
IV	38.27	39.15
VI	52.95	50.85
	100.00	100.00

SiO_2	50.02
Al_2O_3	20.89
(FeO)	5.87
MgO	1.36
CaO	6.89
Na_2O	6.86
K_2O	8.10
	100.00

[1] F. L. RANSOME, *Am. Jour. Sci.*, Vol. V, p. 370, 1898. H. S. WASHINGTON, JOUR. GEOL., Vol. V, p. 376, 1897.

calculate the volumes of the several spherical shells, which must also be assumed to represent the true ellipsoidal ones. The results are given below, including the relative volumes and weights (obtained by correction of the former for specific gravity), and the average composition deduced from this latter.

This result is notably less basic than the former calculated from the curves, and approaches somewhat closely to the compositions of the foyaite and the arkite, though in a general way intermediate between the two. This is so, since these two form (on this basis) 90 per cent. of the whole. It must be remembered, however, that this method is not based on curves, but on a succession of steps, and that the influence of the greater width of the more acid phases is intensified by their greater distance from the center. At the same time both methods indicate a magma rich in Al_2O_3, CaO and alkalis, low in SiO_2 and MgO, and with moderate iron.

Inasmuch as there must be a (probably rather large) correction made for the greater mass of foyaite, on the analogy of the Shonkin Sag laccolith, all these figures can, for the present, be regarded as only suggestive and illustrative of the method of investigation proposed, than representing exactly the actual state of affairs.

It is of course hazardous to theorize on such limited data as are yet available, but the methods indicated in Pirsson's paper and the present one would seem to be of not uncommon applicability, and well worth further trial in the investigation of other favorable localities. Indeed, as Pirsson has remarked,[1] "it would seem as if this should be the point of departure in the study of other series." The methods indicated certainly put the study of rock differentiation upon a purely mathematical basis, which in the hands of a competently mathematical petrographer, should surely lead to an exact quantitative knowledge of the laws which control this, and very probably, with the aid of physical chemistry, to a knowledge of the rationale of the process.

[1] PIRSSON, *op. cit.*, p. 576.

In my former paper I suggested as an explanation of the exceptional character of the Magnet Cove and Umptek laccoliths, in having the borders more acid than the centers, that the arrangement depended on the general chemical character of the undifferentiated magma. The process of differentiation was conceived to be, at least for such small bodies, in great part, a sort of fractional crystallization, the magma being regarded as a solution, so that, in accordance with the laws of cooling solutions, the solvent (*i. e.*, the portion present in excess) crystallizes out first around the borders on cooling of the mass.

From what has been learned of the composition of the magma, it is evident that, even though low in silica, it was originally of a decidedly leucocratic character. In other words, the potential feldspathic and feldspathoidal constituents predominated very largely over the calco-ferromagnesian. This is seen plainly from the relative weights of the spherical shells, but even the more basic composition derived from the curves shows the same thing. Thus the composition with 47.24 per cent. of SiO_2 may be obtained approximately by several different mixtures of all or some of the types analyzed, but in every case it necessitates taking from six-tenths to eight-tenths of foyaite, or foyaite and arkite. It seems scarcely necessary to give these calculations, which are purely empirical. The same composition may also be reduced to mineralogical composition in several ways, according to the assumptions made, but here, also, we get about two-thirds of leucocratic minerals.

The original body of magma, then, at Magnet Cove was, notwithstanding its low silica, decidedly leucocratic, as demanded by the theory, so that the alumina and alkalis, with the proper amount of silica for the formation of feldspar and feldspathoids, playing the rôle of solvent, would crystallize first, and hence form the outer portion of the mass.

The latest paper by Weed and Pirrson, already cited, is of great interest in this connection. Here it is shown conclusively that in the well-dissected Shonkin Sag laccolith the outer melanocratic shonkinite is present in enormously greater quantity

than the core of syenite, which, though basic, is distinctly leucocratic. The composition of the whole, then, would be melanocratic, as demanded by the theory, though with notable amounts of alkalis and alumina. The same general relations are assumed by analogy for the previously described Square Butte laccolith, whose magma thus possessed a similar strongly melanocratic character, *i. e.*, with a basic "solvent" portion, as was suggested.[1]

In this connection attention may be called to two other examples of differentiated masses in which the borders are more acid than the center. One is the igneous area at Alnö,[2] which is of special interest, since the rocks of this locality are very much like those of Magnet Cove. Another example is that of the Rieserferner massif in the Tyrol as described by Becke.[3] The central part of this is a typical tonalite, while the borders are composed of what is called "Randgranit." Although, unfortunately, no analyses are given, it is very evident from the descriptions and from the separations by heavy solutions that the border rock is decidedly higher in alkalis (especially potash) and silica than the main central mass.

Another region which offers close analogies in many ways with that under discussion is that of Ice River, in British Columbia, the rocks of which, collected by Dr. G. M. Dawson, have been briefly noticed by A. E. Barlow.[4] As the specimens were collected on a hasty trip, nothing is as yet known of their mutual relations in the area, but they form an unbroken series "from the most basic ijolite containing 36.988 per cent. of silica, to ordinary nepheline and sodalite syenites containing 53.638 per cent. of silica." Through the kindness of Dr. Barlow I have been able to examine sections of the ijolite, and it is interesting to note that, while closely analogous to the ijolites of

[1] H. S. WASHINGTON, *op. cit.*, p. 411.

[2] HÖGBOM, *Afh. Sver. Geol. Unders.*, No. 148, 1895. Map II. This is explained by Högbom as due to melting and absorption of the surrounding gneiss.

[3] F. BECKE, *Min. Pet. Mitth.*, Vol. XIII, p. 379, 1893.

[4] A. E. BARLOW, *Science*, N. S., Vol. XI, p. 1022, 1900.

Finland and Magnet Cove in most respects, yet that here hornblende replaces augite, thus differing from other known occurrences of this rock. It seems probable that these rocks are not as rich in lime as those of Magnet Cove, but higher in MgO and FeO.

In regard to the possible fourth type of laccolithic differentiation, which was mentioned in my previous paper, namely, that with a gabbroitic or peridotitic or pyroxenitic composition, the suggestion may be advanced here that representatives of this are to be found in the numerous sheets and dikes of diabase, which, as is well known, seldom show marked differentiation between the borders and the center. This is in accord with the view that in these masses the "basic" solvent is present to the almost total exclusion of the feldspathic portion.

As Pirsson has already pointed out,[1] the viscosity of the magma has an important bearing on the form assumed by an intruded mass. The highly viscous acid magmas will tend to arch up the overlying strata and form high laccoliths, while the more fluid, basic magmas do not possess sufficient viscosity to do this in general, and will hence form relatively thin intruded sheets. But, at the same time, many of these sheets are of thickness sufficient to allow of differentiation, if that had been possible through the composition of the magma.

Such sheets, then, may be regarded as the basic homologues of the acid, undifferentiated laccoliths of the Mt. Henry type, differing in form, but like them in that the solvent is largely in excess in the magma, and hence not susceptible to differentiation.

The abnormality of covite has been briefly noted, and a few words must be devoted to it before bringing this paper to a close. It will be observed on reference to Diagram 2 that for this rock the positions of SiO_2, Al_2O_3, Na_2O, and K_2O are below the corresponding abscissal points of the "normal" curves, while those of (FeO), MgO, and CaO are above. In other words, the positions of all the constituents of covite are consistently inversions of what may be called the normal (for Magnet

[1] L. V. PIRSSON, *Eighteenth Ann. Rep. U. S. Geol. Surv.*, Pt. III, p. 586, 1898.

Cove) ; where the curve actually ascends, these would cause it to descend, and *vice versâ*.

Three explanations may be advanced for this. The first is, assuming that the covite is a primary differentiation product like II, III, IV, and VI, that the course of differentiation was not regular, but subject to comparatively large variations of an irregular character. This seems to be unreasonable *a priori*, and is also rendered untenable by the great regularity of the curves, if this type be left out of account, by the fact that the abnormalities are systematic in direction, and correspond inversely to the general characters of the respective "normal" curves, as well as by the field relations of this rock.

Another explanation is that the covite is a mixed rock, produced by the combination of either two differentiates of the magma, or one of its differentiates with foreign rock. That it cannot have been produced by mixture of arkite and foyaite is clear from the fact that many of its constituents are not intermediate between those of these two. It might have been produced by a mixture of foyaite and either ijolite or biotite-ijolite though its position in the complex militates strongly against this view. That it is not due to a mixture of the magma, or parts of it, with the country rock is evident from the composition of the latter, which is too low in MgO and CaO to form covite from foyaite, and too poor in alkalis to form it from the more basic members. Its position in the mass, between the foyaite and arkite, not on the extreme border, is also adverse.

The last, and most probable, hypothesis is that the covite is not the result of the primary differentiation which produced the other types, but of a secondary differentiation of one of the differentiaties of the primary process. In such a further differentiation we would expect the same oxides to differentiate in directions like those of the primary process, but in an intensified degree. This, in the case of the more basic of the two complementary secondary differentiates, would give rise to just the abnormalities noted in regard to covite.

Of just what particular phase of the primary differentiation

this secondary differentiate is a product it is a little difficult to say, but the evidence of Williams's descriptions, my own observations, and the mineralogical and chemical data, indicate that it was the foyaite sub-magna (VI) which has undergone this further change.

If this view be correct there must exist a complementary differentiate, a rock in which the positions of the various oxides are, as regards the "normal" curves, inverse to those of covite. That is, the loci of silica, alumina, and the alkalis would be above, and those of iron oxides, magnesia, and lime would be below, the "normal."

Whether we actually find this rock or not is more or less an accidental matter of erosion, etc. But a chemical analysis indicates that such exists in the case of the "foyaite" which occupies the small area in the northeastern part of the main mass, which was erroneously colored as ijolite on Williams's map.[1] This is a white, coarse-grained, holocrystalline rock,

	I	II	III	IV	Ia
SiO_2	53.54	53.09	49.70	53.11	.892
Al_2O_3	23.95	21.16	18.45	23.62	.234
Fe_2O_3	1.11	1.89	3.39	1.36	.007
FeO	1.24	2.04	4.32	1.47	.017
MgO	0.08	0.32	2.32	0.33	.002
CaO	0.71	3.30	7.91	1.51	.012
Na_2O	8.62	6.86	5.33	8.25	.139
K_2O	8.87	8.42	4.95	8.43	.094
H_2O (110°+)	1.09	1.13	1.09	....	....
H_2O (110°−)	0.14	0.24	0.25	....	....
CO_2	0.20	0.82	none	....	....
TiO_2	trace	0.11	1 33	....	....
P_2O_5	....	0.15	0.40	....	....
Other constituents	....	0.95	....	1.82	....
	99.55	100.48	99.44	100.00	

I. Foyaite, northeast part of area.
II. Foyaite, Diamond Jo quarry.
III. Covite, schoolhouse, western part of area.
IV. Mixture of eight parts of I, and one of III.
Ia. Molecular ratios of I.

[1] *Cf.* H. S. WASHINGTON, *op. cit.*, p. 394, note.

composed of alkali feldspar, with nephelite (partly altered to cancrinite), and rare grains of aegirine-augite. The position of this, outside the zone of arkite, is where we would look for such a differentiate of the foyaite magma.

The analysis, made by myself, of this rock is shown in I above, those of the primary foyaite and the covite in II and III, the molecular ratios of I being given in Ia, for comparison with those of the others on a preceding page. It will be seen that the values obtained for the main Diamond Jo foyaite, which is quite typical of this rock found around the border, are intermediate in every case between those for the other two rocks. Reference to Diagram 2 will also make evident the fact that the positions of the various oxides would be, as regards the normal curves, exactly the inverse of those of the covite. The figures for the new analysis fall above or below their respective curves, where those of covite are below or above. This is just what would be expected in the case of secondary differentiates, as has been explained above.

The results of a mixture of eight parts of I and one part of III are shown in IV. It approximates fairly well to the composition of the typical foyaite, especially in SiO_2, MgO, and K_2O, though Al_2O_3, and Na_2O are considerably higher, and iron oxides and CaO lower.

It may be of interest to give the calculated mineralogical composition of I, which works out as follows:

Orthoclase	52.3
Nephelite	36.9
Cancrinite	2.8
Aegirite	3.2
Diopside	3.7
Extra alumina	1.0
	99.9

The possibility of a secondary differentiation taking place in a primary differentiate is, it must be conceded, difficult to reconcile with the hypothesis already advanced, since according to this the differentiation takes place by a successive crystalliza-

tion, *i. e.*, solidification of the magma, and any such process is, of course, impossible in a solid mass of rock.

This difficulty, however, does not seem to be insuperable. The evolution of heat on the solidification of molten lava is a well-known phenomena, having been actually observed, and the same has been experimentally verified, and the amount of heat evolved on the solidification of diabase has been determined by Barus.[1] Therefore the crystallization of minerals from a molten magma is an exothermic change.

It is therefore conceivable that the solidification of a laccolithic mass may give rise to sufficient heat to remelt portions of it, which might easily remain liquid long enough for a secondary differentiation to take place. That this was actually the case at Magnet Cove cannot be definitely shown, but it is at least an explanation which has a certain degree of probability in its favor.

In regard to problems of interpolation and extrapolation, by which Pirsson obtained such close agreement between calculated and observed chemical composition, we are not in a favorable position, since the analyses which I have made exhaust the known main types of abyssal rocks at the locality. A comparison of the analyses of the dike rocks given by Williams with the curves in Diagram 3 confirms the supposition expressed in my former paper that the tinguaites and the nephelite-porphyry are aschistic, and that the fourchites and ouachitites like the covite, are diaschistic.

It was expected that the analyses of the Fourche Mountain pulaskites would fall in with the curves as laid down. But, determining the abscissal position by silica, it is found that Al_2O_3, Na_2O, and K_2O are below, and (FeO), MgO and CaO are above, what would be their "normal" positions, as will be seen on reference to the diagram.

Although these rocks are unquestionably derived from the same general magma, yet, as their distance from Magnet Cove is about forty miles, it is clear that we need not be surprised to

[1] C. Barus, *Am. Jour. Sci.*, Vol. XLIII, p. 56, 1892.

find discrepancies, due to differences in the process of differentiation.

At Magnet Cove we have, without any doubt, the results of the differentiation in place of a small body of magma. This particular mass may have had originally the composition of the magma underlying the whole region, or it may have been itself a differentiate of this. Differentiation in such a large body of magma as that underlying the whole igneous region of Arkansas would naturally be likely to give rise to diverse products at different points, in which, however, could still be traced some of the original general characters of the whole. We are as yet scarcely in the position to deal with such intricate and obscure problems, but the results of Pirsson's investigations and of those embodied in the preceding pages seem to furnish a promising means of attack.

HENRY S. WASHINGTON.

PECULIAR EFFECTS DUE TO A LIGHTNING DISCHARGE ON LAKE CHAMPLAIN IN AUGUST 1900.

AFTER a period of long continued drought, when the ground was very dry, a thunder shower arose in the Adirondacks, which passed east, crossing Lake Champlain over Westport and along south of the crest of Split Rock Mountain. No rain fell north of the top of the mountain, but a very severe storm passed to the south. When the storm had nearly disappeared, a sudden discharge of lightning passed down from the clouds, striking about half way down the northern slope of the mountain, entirely outside of the rain area and into the dry trees and rocks. In about a half a minute a cloud of what appeared to be dust could be seen rising from among the pines and juniper bushes. This, however, in a couple of minutes proved to be smoke, and in less than five minutes a very well developed forest fire was under way. Fortunately, a number of persons saw the discharge and saw the fire start, and immediately hastening to the spot were able to extinguish the fire before it had burned over more than a small fraction of an acre.

The peculiarity of the discharge was immediately observed upon coming upon the locality. An old pine tree seemed to have received the most severe part of the discharge and was badly split in the familiar manner. In addition to this, however, a number of places were immediately noticed where the lightning had struck either into the rocks or into the dirt overlying the rock. In two cases the discharge into the rock was of such force as to split the rock, tearing up fragments weighing as much as fifty to one hundred pounds and scattering them about. In other places the discharge upon the rock was comparatively slight, producing simply small fractures in the rock, and in some cases the effect was so slight as to simply remove the dry moss, leaving a small white spot not as large as the finger-nail. These partial

discharges of such varying force were scattered over an area of perhaps thirty to forty feet square, the more violent ones being within twelve or fifteen feet of each other. Upon examining the point at which any one of these discharges struck, a white incrustation was apparent upon the rock, as if white paint had either been spattered about or had been spread over as a rough, branching, straggling line. These white incrustations, in some cases, could be traced for a foot or more down into the cracks between the rocks. In other cases, they were mere spots. These white streaks were, undoubtedly, the paths along which the electricity ran, and a superficial examination showed that the white was due to an incipient fusion of the surface of the rock. Unfortunately, it was not practicable to get satisfactory photographs of these markings or to bring in large specimens. Small specimens, however, were brought in, and have been subjected to investigation.

The probable explanation of the scattering discharge of this particular lightning is to be found in the extreme dryness of the ground. The cloud charged with electricity would, of course, induce the opposite kind in the trees and rocks immediately beneath it. Then, when the discharge came, it was necessary that each prominence should discharge to the cloud *individually*, because the ground connecting the different prominences was too poor a conductor to rapidly collect the quantities of electricity and discharge them through a single point, as is usually the case.

WILLIAM HALLOCK.

COLUMBIA UNIVERSITY,
New York City.

A STUDY OF THE STRUCTURE OF FULGURITES.

SOME obscure problems in structures occurring within artificial and natural glasses (rhyolites, tachylites, etc.) receive light from the study of fulgurites, as representatives of instantaneous fusion, and frequently, as it will be shown, of equally rapid devitrification.

Hitherto, however, a constitution of homogeneous glass has been universally observed, under the microscope, in all sand-fulgurites, without the least trace of devitrification in the largest masses.[1] Occasional cloudy stains of brown iron-oxide and black manganese-oxide have been noted, and frequent enclosure of remnants of quartz-grains[2] and of bubbles, both more abundant near the outer walls of fulgurite.[3] In rock-fulgurites, a single instance of devitrification has been recorded. The results of examination of four fulgurites will now be described.

I. *Fulgurite* (lightning-tube) from sand, *Poland;* a small fragment, together with thin cross-sections, prepared by Mr. James Walker, of the New York Microscopical Society. This fulgurite is of small size, from 5 to 8^{mm} in diameter, with central aperture or lumen usually 2.5 to 4^{mm} in diameter, and glass wall varying mostly from 0.6 to 2.0^{mm} in thickness, roughened outwardly by adhering sand-grains in a continuous coating. The photomicrographs (Figs. 1 and 2) may serve to explain certain features as yet unrecognized in other fulgurites.

The wall presents, under low magnifying power, an apparently homogeneous glass, streaked by occasional cloudy wisps

[1] "A Perfect Glass," ARAGO (*Ann. d. Ch. et. d. Phys.*, Vol. XIX (1821), p. 290) and all later investigators.

[2] VON GÜMBEL, *Zeits. d. D. geol. Ges.*, Vol. XXXIV (1882), pp. 647–648.

J. S. DILLER, *Am. Jour. Sci.*, Vol. XXVIII (1884), pp. 252–258.

G. P. MERRILL, *Proc. U. S. Nat. Mus.* (1886), p. 84.

[3] Best shown in the longitudinal and cross-sections of a sand-fulgurite by A. WICHMANN (*Zeits. d. D. geol. Ges.*, Vol. XXXV (1883), Pl. XXVIII).

of brownish and reddish iron-stains, and besprinkled with swarms of bubbles of varying size.

The inner surface of the lumen is for the most part smooth and shining, with boundary sharply defined in cross-section

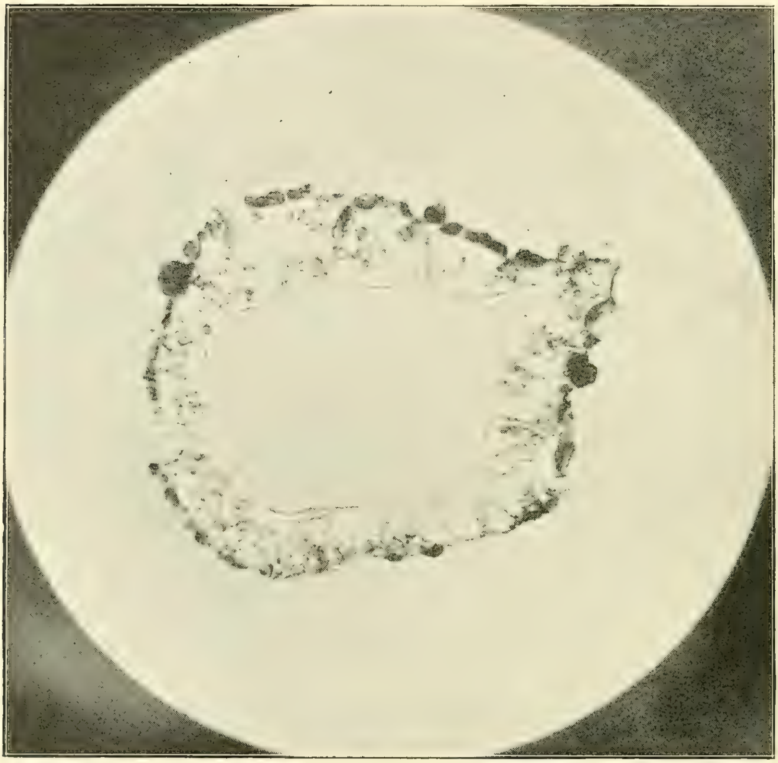

FIG. 1.—Sand-Fulgurite, Poland. × 10. Photomicrograph of cross-section.

(Fig. 1), as in other fulgurites; but, here and there, a few points, pustules and needles of glass are found to project, of a length up to 0.17^{mm}. For the origin of the central lumen an explanation long accepted has been that suggested by Watt for the hollows in a fulgurite-mass, "the expansion of moisture while the fusion existed.[1] In this cross-section the outline is

[1] *Phil. Trans. Roy. Soc. Lond.*, Vol. LXXX (1790), p. 302.

nearly circular, with maximum and minimum axes as 4 : 3 ; in another it is still more elliptical. This difference, common in sand-fulgurites, has been attributed to distortion of the tube by pressure of the surrounding sand upon the fulgurite while still plastic. In one cross-section, one side of the tube appears partly crushed together, with coalescence of opposite parts of the wall into a blebby mass of coarse bubbles and partial obliteration of the lumen. The characteristics of such a fulgurite seem therefore to be naturally divided into those developed during the sudden dilatation of the tube, and those which may have ensued during its quick compression and in places partial collapse.

In regard to the distribution of the bubbles or vesicles, three vaguely marked bands may be distinguished :[1] a marginal tract, next the lumen, comparatively free from vesicles and clear : a middle portion of the wall comprising most of the larger vesicles ; and the gathering of dark swarms of the more minute vesicles toward the outer margin.

The last (partly shown in Fig. 2) vastly predominate in number over the larger vesicles, are almost universally spherical, vary greatly in diameter down to 1μ or less, and compose the dark clouds, seen under low magnifying power, on inner side of sand-grains adhering to outer side of the wall. Others are also dispersed more irregularly in lines and bands through patches of the glass (best shown under magnifying power of at least 300 times). A careful search was made among these dark bubbles, particularly the most minute, by means of a tenth-inch objective of good definition, for traces of enclosed water, but no liquid could be distinguished. From this I conclude that any watery vapor, derived from moisture present in the sand, has been mostly expelled in the explosions, and also that this has probably had far less to do, in expansion of the lumen and formation and compression of bubbles, than the elastic force evolved by sudden heating of the large volume of air occupying the interstices of the

[1] In a fulgurite from Milton, Florida, no definite order of arrangement occurred. (MERRILL, *loc. cit.*, p. 90).

sand-grains. The bubbles should therefore be more properly denominated air-vesicles (*luft-blasen*) than vapor- or steam-cavities (*dampf-poren.*)

The larger vesicles, which mostly occupy the middle part of the tube-wall, seem to have been produced by crowding together

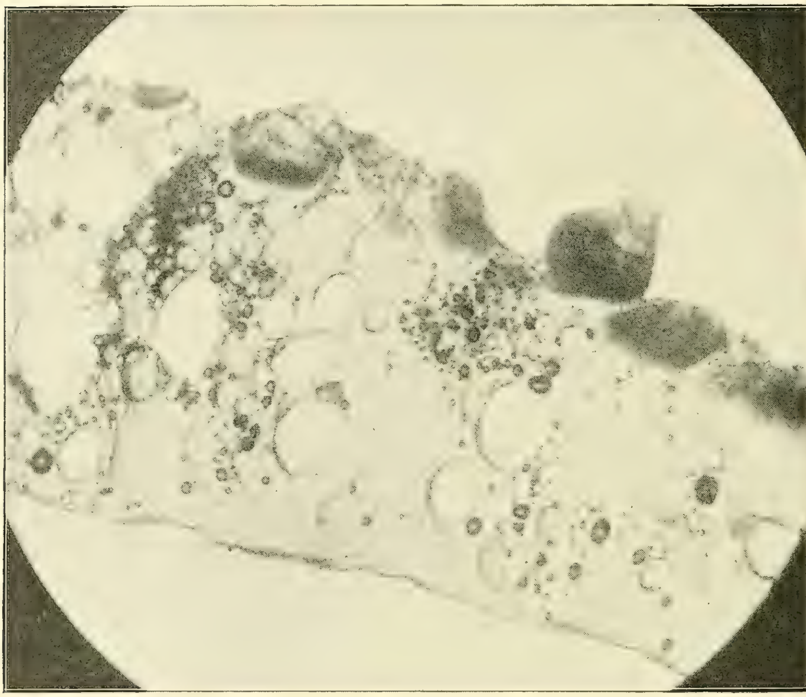

FIG. 2.— The same. × 50. Part of wall.

and coalescence of smaller ones. The largest, which have been perforated and emptied, in making the thin section, present light outlines, up to 0.2 to 0.3 ^{mm} in diameter, mostly elliptical, but also oval, pearshaped, lenticular, triangular, or squeezed together in groups, with contiguous walls flattened by pressure in direction tangential to the tube-wall. Even a particular vesicle may vary much in size and in form of cross-section at different depths, as if distorted after formation. The longer axes of the

elongated vesicles are in general disposed radially[1] toward the lumen of the tube, though occasionally one may lie obliquely or even at right angles to that direction, as if twisted around by a sudden thrust. All the facts seem to point to strong lateral or tangential compression of the vesicles within the surrounding glass wall, and to their consequent extension and distortion in the direction of relief.[2]

The sudden expansion of air and vapor by the electric discharge has thus effected the dilatation of the lumen, the generation of bubbles throughout the fused glass, and the coalescence of those first formed into the larger vesicles. The relief of this tension outwardly, toward the margin of the tube, first caused the radial elongation of the larger vesicles and extension of conical projections and wings from outer side of the plastic tube, aided, doubtless, by lateral offshoots of the electric current.[3] Then, in the moments succeeding the passage of the main current, the effects of sudden condensation, lateral contraction and recoil are shown in the instances of partial collapse of the tube, in the reverted distortion of vesicles, *i. e.*, inwardly toward the lumen, and in explosion of some bubbles nearest the lumen into pustules and points of glass over its surface. Where the glass retained its plasticity longer, the vesicles have recovered their normal spherical form; this condition seems to have been regained in nearly all fulgurites whose vesicles have been carefully examined by others. It is to be noted that elongated vesicles in radial position have been recorded in only two cases of rock-fulgurites, in both within partially devitrified glass, as found in one by Rutley and in the other by Wichmann; in the latter case (viz., fulgurite III, beyond) I have made the same

[1] A position already recognized in other fulgurites by Wichmann and Rutley.

[2] One writer considers "this radial arrangement . . . . possibly indicative of a rudimentary crystallization in the fulgurite glass" (RICHARDSON, *Min. Collector*, Vol. III (1896), p. 132).

[3] MERRILL, *loc. cit.*, 87. One consequence of these offshoots, and of the ozonized atmosphere thereby developed, is shown in the reddish stains, due to oxidation of iron, in the sand surrounding a fulgurite, to the distance of 3 or 4 inches; *e. g.*, in that found near Starczynow, Poland (ROEMER, *N. Jahrb. f. Min.*, 1876, pp. 33–40).

observation, in addition to fulgurites I, II, and IV. Their exclusive association, therefore, with devitrification may be a consequence of more sluggish movement and imperfect recovery from distortion within the more viscous crystallite-laden glass.

Another feature, quite distinct in the vesicles of larger size, is the separation of each from the surrounding glass by a limpid pellicle, never exceeding 0.2μ in thickness. This appears both in cross-section, with sharply differentiated outlines, and also in jagged remnants around the margin of an emptied vesicle, on surfaces of the thin section, like the edges of a broken eggshell. It may be considered a glass coating, suddenly chilled and condensed in contact with the bubble, at first consolidation of the tube-wall.

Around the outer margin of the wall occurs, as usual in sand-fulgurites, a continuous row of adhering sand-grains (Fig. 1), semi-fused and to that extent rendered white and opaque. These grains are partly rounded and from 0.2 to 0.6^{mm} across. All were successively examined around the thin cross-section by the usual optical methods, those of feldspar being generally recognizable by traces of cleavage, cloudy alteration, oblique extinction, lower interference-colors than those of quartz, and more or less complete biaxial interference-figures, whose negative character could often be distinguished. Out of 35 grains 23 were identified as orthoclase, the remainder as quartz. In the more angular grains wavy extinction testified to remaining mechanical stress. The indications are that the original sand was very fine and highly feldspathic, free from mica and with few ferruginous particles.

While the outer extremity of a sand-grain, so attached to the glass wall, often retains its translucency and color entirely uninjured by the electric discharge, this is sharply divided from an altered milk-white inner portion, in which the change consists mainly, with quartz, in very minute fracturing and consequent opacity. This passes, with feldspar, into a translucent border, next the glass, in which minute needles or crystallites abound, suggesting immediate devitrification after fusion. From

this border very irregular milky threads descend into the glass in a confused network, swarming with the most minute air-bubbles, approaching 1 or 2μ in diameter. In this vicinity, also, fibrous threads or streaks of glass occur, which display, between crossed nicols, feeble colors of aggregate polarization.

On reception of this fulgurite from Mr. Walker, he stated: "I have noticed in several places on the outside of the tube . . . . some very fine threads of fused quartz, like delicate spider-webs, connecting the sand-grains, as if the partly fused grains had been forced apart while still soft." This new feature in fulgurites I can confirm. The glass threads are colorless, brownish, or sometimes black; generally smooth and glistening, but occasionally roughened; more or less curved; passing from grain to grain of the adhering sand, but sometimes projecting as if broken; mostly 0.4 to 1.1^{mm} in length, and 0.015 to 0.04^{mm} in width.[1] In the glass between neighboring sand-grains many minute round holes are also perceptible[2] under a low magnifying power, apparently produced by exploded bubbles. In several cases, in the glass behind a sand-grain, there is a limpid band with faintly marked outline (best shown in photomicrograph, Fig. 2), the latter corresponding to the back contour of the sand-grain. This must mark its original position before it was jerked outward to a distance of half its diameter and the space behind filled in at once with clear glass, distinct because free from bubbles. To the force and extent of this outward jerk, in some instances, the glass threads doubtless owe their formation.

Between crossed nicols the thin section at first appears dark, like a homogeneous glass, with the exception of the ring of highly refracting sand-grains outside and occasional gleams of reflection from scattered air-vesicles. In ordinary light, under

[1] A coating of sublimed silica is often found upon the carborundum crystals manufactured in the electric furnace at Niagara Falls. The interlaced threads of quartz of which it is composed much exceed the dimensions of the natural threads above described. They differ also in the variation of diameter in a thread and in the common occurrence of a peculiar beading along many threads.

[2] MERRILL, *loc. cit.*, p. 84.

low magnifying power, a faint granulation is discernible throughout the glass. This is resolved under higher power (× 300) into an irregular, sparse to abundant distribution of crystallites through a predominant glassy base, from the margin of the lumen to the fusion-border of the sand-grains. No special concentration occurs, except in occasional richer wisps and streaks, like diffusion-streams, across minute patches of clearer glass. In general they are scattered in the same way among and near to the air-vesicles. In some cases, however, an elongated vesicle is surrounded by a band of perfectly clear glass, free from microlites, 5 to 10 μ in width, which broadens to 20 or 30 μ opposite the ends of the major axis of the vesicle. This has been plainly due to compression and extension of an original envelope of viscid glass, chilled and consolidated by proximity of the vesicle, before devitrification could take place within this envelope. But in general throughout the glass we may recognize one condition that has favored crystallization, in the influence of absorbed vapors, through the abundantly intermixed bubbles.[1]

These microlites are straight or curved, sometimes lath-shaped, less than 1 μ in length in some cloudy aggregates, but largely 3 to 13 μ, or even extend into threads, often bent or crooked, 30 or 40 μ in length. They lie in all positions and never display any fluidal arrangement,[2] though the larger number seem to be radially disposed toward the center of the fulgurite-tube. Between crossed nicols the microlites exhibit very feeble double refraction, mostly pale gray, here and there brightening into pale greenish-white of the first order. All these forms appear to represent the regeneration of feldspar. A very few margarites were also distinguished, and one spherulite

[1] As in the pumiceous glass of the fulgurite of Little Ararat III, as well as in the devitrified glass of Monte Viso, of which Rutley states that the vesicles are sometimes so closely packed that the glass is quite spongy. However, the pumiceous glass of other fulgurites has been found entirely homogeneous.

[2] In fulgurite-lumps from Florida, Merrill recognized a fluidal structure in the homogeneous glass near bubbles, "as if by sudden expansion of a steam-bubble in the plastic material" (*loc. cit.*, p. 87).

of about 3μ diameter, made up of concentric shells, which exhibited a faint cross, remaining fixed on rotation.

This unique occurrence of devitrification in the glass of a sand-fulgurite is perhaps mainly connected with the high proportion of feldspar in the original sand. Such a chemical constitution must have approached that of the rhyolite[1] used in the experiments of Barus and Iddings, whose viscosity and whose electric conduction, when fused, were both found to exceed those of the less acid rocks, and led to the conclusion that "electric conduction increases with the degree of the acidity of the magma. . . . . Since fusibility decreases in a marked way as the composition of the magma approaches pure silica, it follows that, in a series of different magmas, electric conduction at any given temperature increases in proportion as the viscosity increases." From this it must be inferred that the more quartzose sands, when once melted by a lightning stroke, have offered the viscous medium of readiest passage to the current.

Exception has been rightly taken, however, to the assumption that the material of a fulgurite-tube was necessarily or entirely "quartz-glass."[2] The general distribution of feldspar in notable quantity through ordinary sands is a fact in favor of the suggestion of Wichmann and Harting, that the minerals of comparatively ready fusibility have served as flux and thus ended in reducing the more refractory. Particularly then in this fulgurite do we need to consider not only the relative fusibilities of feldspar and quartz, but also the relative degrees of their solvency in contact with the first formed portion of molten glass, doubtless so instantaneous in formation as to be independent of all differences in fusibility, solution, conduction or any other property of the various sand-grains.

To throw light on this question and on the variations, recorded beyond, in devitrification of such natural glasses, a

[1] Silica, 75.5 per cent.; alumna, 13.25; soda, 4.76; potassa, 2.85, etc. Heated in a platinum crucible, it melted at 1500° C., was very viscous (" a stiff paste ") even at 1600°, and quite viscid at 1700°. *Am. Jour. Sci.*, Vol. XLIV (1892), pp. 242–249.

[2] See V. GÜMBEL, *loc. cit.*, and *idem.* Vol. XXXVI (1884), pp. 179–180, and criticism by A. WICHMANN.

preliminary examination was made of a specimen of artificially vitrified gneiss, with brown glassy fracture, obtained from the hearth of a limekiln at Tuckahoe, N. Y. This had been evidently thoroughly roasted and deprived of moisture but not fused (as the gneiss structure still perfectly survived, in the undisturbed parallel biotite-scales), saturated with slag from the kiln, and finally thrown out and slowly cooled upon the refuse-dump. In a thin section under the microscope, the results of the action of fused glass upon the original minerals of the gneiss were found to be as follows: a slight solvent attack upon the biotite, rendering it in part opaque, with brown haloes and cloudy wisps of iron oxide feathering out into the adjacent glass, apparently by quiet molecular diffusion; a decided but partial solution of the quartz, of which a small portion survived in angular remnants, still in place; and complete solution and disappearance of the feldspar. The main mass of the saturated rock had thus been converted into pure colorless glass, with a few coffee-colored stains, without any trace of crystallites or new stony matter, notwithstanding its slow cooling. However, globules of clear glass, about 0.5^{mm} in diameter, were abundantly interspersed, colorless like their matrix and with little adherence, since many had become loosened and removed from the surface of the thin section during the process of grinding. It was consequently inferred:

1. That minerals of acidic constitution, feldspar and quartz, may be largely carried into solution, in contact with fused glass, at a temperature below their thermal melting points.

2. That their fused products tend to cohere *in situ* in spheroidal globules, through possession of a different degree of density, viscosity and contraction on cooling, from that of the surrounding glass.

3. That the process of devitrification has been prevented in this vitrified gneiss by the peculiar constitution, probably the acidity, of the unsaturated glass, and by an insufficient period of cooling.

In the development of a sand-fulgurite by almost instantaneous

fusion, it is unlikely that any selective power could have been exerted among the sand-grains, through their slight variations in fusibility, conductivity or other property. All within a radius of a few millimeters were suddenly and completely fused, with a limitation so sharply defined, in this fulgurite, that, in any sand-grain, the quartz or feldspar may remain entirely unaltered within an interval of about 0.02^{mm} of the same material fused and again devitrified. The molten mass of its wall became a supersaturated solution of feldspar, with specially strong solvency, however, toward any external quartz-grains within its reach, through the tendency to form more acid silicate. Such action probably accounts for the increased amount of silica which has been determined in fulgurite-glass over that in the original sand in several instances.[1] In this fulgurite also the preponderance of feldspar over quartz in the attached sand-grains may possibly have become exaggerated by the slower solution of the former mineral.

The view has been advanced[2] that a selective power of fusion has been exerted by the electric current among the grains, but without regard to their fusibility: the poorer conductors (quartz-grains), offering so strong resistance as to become heated to the point of fusion, those substances which are the best conductors (iron-oxides and feldspars) escaping with least injury. It is notable, however, that it is not a good conductor but quartz only which has ever been recognized in remnants of grains inclosed in the glass of other sand-fulgurites, and that no remnants whatever are enclosed within the glass of this fulgurite, apparently because so rich in flux.

Three rock-fulgurites will now be described in the order of increasing devitrification.

[1] In a fulgurite from Union Grove, Ill., silica 91.66 per cent. in the glass to 84.83 in the sand; in another, 95.91 in the glass, to about 90 in the sand. (MERRILL, *loc. cit.*, p. 85.)

[2] MERRILL, *loc. cit.*, p. 87. Diller notes, however, in a fulgurite on hypersthene-basalt, that the sequence of alteration is according to degree of fusibility of the components of the rock, greatest in the groundmass, then hypersthene, then feldspar, and least in olivine.

II. *Fulgurite* on gneiss, near *Split Rock, Lake Champlain, New York;* specimen collected by Professor William Hallock, of Columbia University, immediately after the lightning-stroke, as described in his accompanying article. Thin sections of this granite-gneiss were prepared, one in plane parallel to and within about 0.03^{mm} of the fulguritic crust, the other in cross-section. The rock is found to present a surface somewhat dulled by weathering, and to consist, to about 70 per cent. of its volume, of feldspars, microcline, microperthitic orthoclase and a little plagioclase, besides much quartz and a small amount of magnetite, biotite, garnet, and rutile, but no trace of fulguritic glass. No undulatory extinction occurs between the nicols, as evidence of strain.

The fulgurite-pellicle is entirely superficial,[1] brittle, and with slight adherence to the rock, from 0.1 to 0.3^{mm} in thickness, nearly white, consisting chiefly of a minutely blebby hyaline crust with blistered, glistening surface, whose bubbles, rarely exceeding 0.2^{mm} in diameter, are nearly spherical but somewhat elongated normally to the surface of the rock. On careful examination of these, in a flake mounted in balsam, under a good tenth-inch immersion objective, no water of condensation could be detected in any vesicle.

Many short glass-fibers occur, sometimes with globular ends, resembling some of those in "Pele's Hair" from the crater of Kilauea, Hawaii. This white pumiceous slag is quite uniformly attached to the predominant surfaces of feldspar, though pierced by the uncovered gray grains of quartz. It is dispersed over the rather even surface of the hard gneiss in radial, somewhat dendritic forms, often many inches in length, thinning out into feathery fleeces at the margins. Wherever these pass over minute plates and seams of the dark minerals of the rock, the blebby fulgurite assume a yellow, red, brown, or black color, as a dark enamel, or in the form of tiny spherules.[2]

[1] Similar superficial films of fulgurite have been often observed, by Humboldt in Mexico, by Brun in the Alps, by Ramond on mica-schist, on limestone, and on phonolite in the Pyrenees and Auvergne.

[2] Over the fulgurite-crust on hornblende-gneiss at Mount Blanc distinct white and

The white material, when flaked off and mounted in Canada balsam, reveals a limpid glass, dispersed with very few and minute straight microlites and very rarely rhombic plates; the latter display rather bright interference-colors between crossed nicols and parallel extinction.[1] Where thinnest, the glass remains isotrope and dark, while the thicker portion, generally toward the center of the flake, glows with the greenish-white of the first order of Newton's colors; in places the color reaches the sky-blue of the second order, exactly like a thin scale of the underlying feldspar. The indications are that devitrification had begun, throughout the glass, in globulites too extremely minute for distinction, even under high magnifying power, but whose concentrated effect in depolarization becomes visible, between the crossed nicols, in the thicker parts of the flakes. The flakes of brown or colored glass, however, are found to be uniformly isotrope. It should be noted that, as the greater thickness of these flakes approaches or exceeds 0.5^{mm}, it is probable that the presence of crystallites might hardly have been recognized in a ground section of the ordinary thinness, 0.02 to 0.05^{mm}. In such an investigation plane surfaces are not indispensable, and the examination of splinters of a glass may serve an important office. Evidences of incipient devitrification, in fulgurites and other glasses, have possibly escaped detection by observers relying entirely on examination of thin sections.

The facts above described lead to the following conclusions:

1. We have here to do with different conditions from those

dark globules were dispersed: "the fused surface of each crystal solidified almost exactly *in situ*, except where sputtering of the molten matter was caused" (RUTLEY, *Quar. Jour. Geol. Soc.* (1885), pp. 152–156). The inclosed globules in the slag-saturated gneiss of Tuckahoe may represent a similar tendency to isolation.

[1] The homogeneity of glass which apparently prevailed in all fulgurites examined by the early observers led naturally to the statement in 1884 that the absence of crystallites "may be used as a means of distinguishing fulgurite from other natural glasses" (J. S. DILLER, *Am. Jour. Sci.*, Vol. XXVIII (1884), pp. 252–258). In 1889, Rutley made the first and hitherto the only record of the occurrence of devitrificatoin in a vesicular fulgurite-glass on glaucophane-schist, at Monte Viso, Cottian Alps. The crystalline forms consisted of globulites, margarites, and longulites, and even symmetrical microliths (*Quar. Jour. Geol. Soc.*, Vol. XLV (1889), pp. 60–66).

which attended the sand-fulgurite I, viz., the lessening force of a divided electric current, passing over the surface of a compact rock-mass. The effect of the electric action on this solid surface of gneiss has been more diffuse, feeble, and superficial than in the sand-fulgurite, and, in this case, confined to the feldspar.

2. The fulgurite crust has been produced almost entirely by fusion of surfaces of feldspar-grains rather than of quartz, and in small degree by that of the iron-containing minerals. The property of fusibility, rather than that of imperfect conduction, has determined the amount of attack on each grain. Each kind of glass, colorless and colored, is sharply confined to the mineral surfaces from whose fusion it originated, with little tendency to intermixture.

3. The bubbles throughout the fulgurite-crust owe their formation chiefly to expansion of air, and in part doubtless of steam, derived from moisture in the weathered surface of the rock. Their sputtering explosion has probably produced the tiny fibers over the blebby surface.

4. The surprising partial devitrification, which has instantaneously followed fusion throughout the delicate white pellicle, has been evidently facilitated by the supersaturated feldspar solution of which the molten glass almost entirely consisted, and by its consequent unstable molecular condition.

III. *Fulgurite* in augite-andesite, summit of *Lesser Ararat, Armenia.* The specimen was one of those collected by Dr. E. O. Hovey, of the American Museum of Natural History, New York.

The fulgurite material from this peak has received repeated study in the field or laboratory by successive observers. Abich[1] detected only pure glass in the fulgurite, but in such abundance that he suggested the name "fulgurite-andesite" for the material on the apex of the peak. Gustav Rose[2] also came to the same conclusion, and determined the difficult fusibility of the

[1] *Sitz. Akad. Wiss. Wien*, Vol. LX (1870), I. Abth., pp. 153–161.

[2] *Zeit. d. D. geol. Ges.*, Vol. XXV (1873), pp. 112, 113.

glass on thin edges. A. Wichmann[1] made the most careful petrographic study of this and other fulgurites and distinguished this as "entirely homogeneous glass," without any alteration of the andesite at the sharply defined contact. He considered the bubbles as vapor-cavities (*dampf-poren*), and gave a clear representation of the structure of a lightning-tube in a well-drawn cross-section. The results of my own examination, which follow, differ in some important particulars.

The augite-andesite of this peak, though consisting of fresh plagioclase-feldspar, with some partly decayed augite, hornblende, orthoclase, and magnetite, is deeply disintegrated by weathering, so that, in some blocks, its grains crumble readily under pressure from one's fingers. It is also traversed, even in the most solid material, by numerous cavities and channels, a few millimeters in width, of most irregular form, crossing and connecting with each other at intervals of a few centimeters. Most of these passages, in the more decayed specimens I have examined, in the collection of Dr. Hovey, are one or two centimeters in width, and often coated by the olive-green fulgurite glass to a depth of 1 to 1.5^{mm}; some are even solidly filled up by the glass, with a cross-section of 5 to 8^{mm} in diameter or over. Other cavities of exactly the same form and size were noticed, adjoining but not connecting, which are now and appear always to have been entirely free from fulgurite. Most, if not all of these, therefore, seem to be preëxisting cavities, later occupied in many cases by fulgurite. A confirmation of this is found, by optical examination of the thin sections, in the absence of undulatory extinction in the grains of minerals adjacent to the fulgurite, *i. e.*, the lack of any indication of strain likely to have resulted from actual perforation of the rock by lightning. On the other hand, certain other specimens in the collection from the same peak are penetrated by cylindrical winding tubes,[2]

[1] *Idem.*, Vol. XXXV (1883), pp. 849–859.

[2] The approximately cylindrical form of the latter, and their curved windings, have been well represented by Rutley, from the fulgurite furrows on glaucophane-schist at Monte Viso, Cottian Alps (*loc. cit.*, plate).

lined or filled with the dark glass, which seem clearly to owe their perforation to the action of electric discharges upon more disintegrated blocks of the crumbling rock.

The glass is found to be rich in bubbles, especially toward and near the surface of the inner rock-wall, and in places even blown up into blebs and blisters. All of the smaller vesicles and most of the larger are approximately spherical. In none of these could any water of condensation be discovered under a tenth-inch objective; their contents appear to be entirely gaseous, *i. e.*, chiefly derived, in all probability, from expansion of air rather than steam. Many of the larger vesicles present a more or less elongated form, with major axis always arranged in position at right angles to the adjacent rock-wall. This distortion of vesicles in the glass of a rock-fulgurite may be always attributed, in my opinion, entirely to the reaction of pressure inward, *i. e.*, toward the lumen, which has instantaneously followed the passage of the electric discharge, mainly from expansion of the collected bubbles, partly from increased volume of the glass during fusion of the rock.

When crushed splinters of the glass are examined, though found sometimes entirely amorphous, as reported by Wichmann and others, it is also in places rich in bunches of stony matter, isolated needles (with bright interference-colors between crossed nicols and parallel extinction) and clusters of microlitic fibers, sometimes radiating around a bubble.

Again, at the line of contact between this glass and the andesite-wall, an intermediate stony layer occurs, 0.15 to 0.70^{mm} in thickness, containing a few obscure outlines of bubbles. This plainly consists of wholly devitrified glass, made up of a felt of irregularly crossing needles, fibrous curved wisps, or straight bundles, some rectangular in form, 0.08 to 0.20^{mm} in length, whose axes lie mostly parallel to the line of contact with the adjacent rock-wall. In the straight bundles an extinction-angle of about 19° is uniformly obtained, often with undulatory phase, and all offer the characteristics of orthoclase. There is a remarkable resemblance, if not identity, of these fibrous aggregates, in

form, structure, and optical character, to the artificial microlitic bundles obtained in the experiments of J. S. Diller (*loc. cit.*) by long fusion of amorphous fulgurite-glass in crucibles.

The difference of the above results from those hitherto reported from study of the fulgurite of this peak may be attributable to variation in the structure of the fulgurite, particularly in regard to devitrification, in different parts of the surface.

IV. *Fulgurite* from summit of *Central Butte, Little Missouri Buttes, Wyoming;* specimen collected by Mr. John D. Irving. This is a small fragment of phonolite, apparently from the edge of intersection between two joints, down which corner the fulgurite runs in a shining, cream-colored, slightly brownish crust, about 15^{mm} wide and 3^{mm} thick. On a fractured cross-section it shows distinct lamination parallel to the surface of contact, as if the latent structure had been developed by weathering.

The rock consists mainly of orthoclase-phenocrysts, whose idiomorphic character is obscured by fractures, imbedded in a smaller volume of granular, somewhat ochreous holocrystalline groundmass, through which needles of hornblende, plagioclase, apatite, and granules of magnetite are dispersed. Between the crossed nicols, the transparent minerals, in a thin section, generally display a decided undulatory extinction, in evidence of condition of strain.

This fulgurite exhibits under the microscope the unique character of a wholly devitrified mass, light brownish-gray, delicately laminated in cross-section (*a*, Fig. 3) by a very irregular flow-structure,[1] with interruptions and intersections of laminæ suggesting those observed in the cross-stratification of certain sand deposits. Some laminæ, especially near the contact-line (*e. g.*, just below c'), are bent and faulted, with ends slipped past each other. The thicker laminæ consist of very minute, colorless

[1] Compare the thin underlying coat, in which fusion is less complete, with dark fluidal banding, and which envelops numerous crystal remnants, described by Diller in the "mixed zone" of fulgurite-glass in immediate contact with basalt at Mt. Thielson (*loc. cit.*). Of this he states, it is difficult to conceive how it has been produced, "unless it is due to the repulsion of the particles among themselves."

needles, fibers, and granules, in an irregular felted mass, through which obscure circular and elliptical outlines (*b*, etc.) indicate the position of numerous original bubbles, now flattened, freed from gas, and even partly obliterated. With this darker material, evidently entirely devitrified glass, there occur frequent

FIG. 3.—Rock-Fulgurite, Wyoming. × 50. Cross-section of contact.

alternations (*d*, *d*, etc.) of thin films of a microscopic breccia or "mylonite," shining brightly between the crossed nicols. This is composed apparently of rock-dust,[1] made up chiefly of angular splinters of feldspar; a few coarser fragments of the same are also irregularly interspersed (*f*). Along the line of contact (*d′*), the same angular dust is drawn out in streaks or gathered

[1] Apparently related to the opaque whitish layer, between the glass and rock, in the fulgurite of Monte Viso, and referred by Rutley to altered titanite.

in embayments. Its origin is well shown next the Carlsbad-twin of orthoclase (c–c'), whose outer end (c'), projecting into the fulgurite current, has been shattered into this dust to a depth of 0.1^{mm}, seemingly after the adjoining fulgurite laminæ had somewhat consolidated. This and other feldspar-grains lying along the edge of the stream, have been completely encircled by fulgurite, with an inner film of angular dust, marking the outline of the minutely shattered surface of feldspar. This micro-breccia is brought out between the crossed nicols in distinct bright stripes. The phonolite groundmass generally shows rather deeper embayments by fulgurite-attack than the feldspar-grains ; but the hornblende-needles seem to lie entirely unaffected, even in immediate contact (h) with the fulgurite-stream.

It is possible that the devitrified crust which constitutes this fulgurite may be a remnant of an inner stony layer (as in Fulgurite III), from which a glass-coating may have been scaled off during weathering; but of the latter there is no evidence, and the stony crust now occurs coated by small lichens. Yet the peculiar structure of this crust, with its alternations of micro-crystalline and of micro-brecciated laminæ, signifies that devitrification has not been a secondary process due to weathering of a glass.

RÉSUMÉ.

Considerable variation appears, in the characteristics of these rock-fulgurites, from two probable causes : the variations in the electric current, in regard to volume, intensity, duration, and a probable series of successive discharges, in some cases, within the same fulgurite (IV) ; and the difference of the rock-material in the three specimens, gneiss, andesite, and phonolite.

In regard to the duration of a lightning-flash, it is understood not to have usually exceeded one hundred thousandth of a second (Sylvanus Thompson). The discharge is known to be oscillatory, surging back and forth, and even in many cases, like that observed by Professor Hallock, apparently persistent and continuous for some moments. Nevertheless, allowing for the

long retention of the image of the flash upon the retina, its duration is rarely likely to have much exceeded the above quoted minute interval.

The results of the electric action are of two classes, superficial and internal.

The superficial consist, in succession, of fracture of outer pellicle of exposed minerals: fusion *in situ* of the surface of more fusible grains: and development of bubbles in the enamel of molten glass from expansion of moisture and air, with frequent explosions and spattering of glass globules.

The internal results comprise the penetration of preëxisting cavities of the rock, and often the actual piercing of surface of outcrop or blocks, if softened and disintegrated by weathering, by lightning-tubes of symmetrical cross-section, as well as passage downward through fissures and joints.

This has been accompanied by fracture and fusion of pellicles over the surfaces thus traversed, especially of the more fusible minerals and groundmass; development of air- and vapor-bubbles in the molten coating; and sometimes, at least, a succession of waves, sweeping downward fused glass and rock-dust, in a series of alternating films, the oldest nearest the rock-wall and subjected to frequent dislocation.

At the moment of cessation of the electric current, there have followed reaction from the intense pressure, expansion of vesicles, and regurgitation of glass upon the surface of the rock from some filled lightning tubes;[1] explosion and disappearance of bubbles nearest the surface, distortion of many by inward relief of pressure, or general recovery of spherical form; and partial devitrification of the glass, occasionally complete, where certain favorable conditions have prevailed — probably the presence of moist air in intermixed bubbles, a supersaturated neutral glass, and an over-heated or slowly-cooling contiguous sheet of rock.

The instantaneous regeneration of feldspar only, in the form

[1] First recorded by HUMBOLDT, in rock-fulgurite on volcano of Nevada de Toluca, Mexico (*Ann. d. Ch. et d. Phys*, Vol. XIX (1821), p. 299.)

of microlites, in every instance, in the series I have examined, seems at first somewhat at variance with the conclusions of Lagorio as to the particularly difficult saturation of a molten silicate by the oxides represented in that mineral. But we have here, apparently, a far different magma from that employed in the experiments of Pelouze, artificial glass, *i. e.*, from every evidence, a supersaturated solution of feldspar in its own fused material. In such a magma-solution, a combination of silica, alumina, and alkali molecules, must find conditions highly favoring ease and rapidity in re-crystallization.

ALEXIS A. JULIEN.

COLUMBIA UNIVERSITY,
New York City.

EXPLANATION OF FIGURES

Fig. 1. Sand-Fulgurite, Poland.— Photomicrograph of cross-section, showing sharply defined outline of central lumen, the glass wall with its vesicles, and ring of dark semi-fused sand-grains, adhering to the irregular outer boundary of the fulgurite. ×10.

Fig. 2. The same.— Photomicrograph of section of part of the wall, showing forms, radial distension, and distribution of the vesicles, the smaller and darker ones still occupied by air. Several of the sand-grains appear along the outer boundary, each with its inner crescent of limpid glass. The inner dark part of a grain indicates the side which has been partly fused; the outer clear part, that which remains unaltered. ×50.

Fig. 3. Rock-Fulgurite, Central Butte, Wyoming.— Drawing of cross-section, showing line of contact (*d'*, *h*, *c'*, *e*) between phonolite, *p*, and fulgurite, *a*.

b. Obscure flattened vesicles.

c–c'. Carlsbad twin of orthoclase, with shattered ends, surrounded by feldspar-dust and devitrified glass, enclosing a few bubbles.

d, *d*, *d*. Films of rock-dust, alternating with laminæ of devitrified glass.

d'. Film of rock-dust along the contact.

e. Projecting corner of feldspar-grain, shattered by the electric current.

f, etc. Feldspar fragments scattered through the fulgurite.

h. Green hornblende needle, unaffected by the fulgurite-stream. ×50.

PHYSIOGRAPHY OF THE BOSTON MOUNTAINS, ARKANSAS [1]

THE highlands of Arkansas lie in the northwestern part of the state, and comprise about half its area. They are divided, physiographically, into a north and a south part by the valley of the Arkansas River. They are also divided structurally into the same parts, the former being a region of horizontally-bedded rocks, somewhat disturbed by faulting and folding, while the latter, known as the Ouachita Mountains, is distinctly a folded region.

This northern division of the Arkansas highlands, with its westward extension into Indian Territory, constitutes the southern part of the Ozark region.[2] In Arkansas, it is divided into a low and a high part, the former extending northward into Missouri, and passing, along its southern border, into the latter, by an irregular but bold escarpment from 500 to 1000 feet high.

It is this latter region that is known in Arkansas as the Boston Mountains. Including that part which lies in Indian Territory, its total length is about 215 miles, about 170 of which is in Arkansas. Its average width approximates 35 miles. On the south, it passes into the valley of the Arkansas River by steep slopes, though less precipitous than those on the north.

These mountains are by far the highest part of the Ozark region as well as the most picturesque. Their highest point, so far as determined, is some miles east of the town of Winslow, on the St. Louis and San Francisco railway, where the altitude is 2,250 feet.[3] From this region of highest elevation, they

[1] Read before Section E of the American Association for the Advancement of Science at the Denver meeting, August 1901.

[2] The Ouachita Mountains have been included by some writers with the Ozarks; but because of the great structural and topographic differences in the two regions, to say nothing of the probable historic differences, this is manifestly wrong.

[3] Topographic map United States Geological Survey, Winslow quadrangle.

FIG. 1.—Photo from Branner's relief map of Arkansas.

gradually fall off to the east, sinking below the Tertiary deposits just west of the St. Louis, Iron Mountain and Southern railway and south of White River; also from this region of highest elevation, they fall off westward to the Grand River in Indian Territory.[1] It will be seen that the east-west line along the crest of these mountains forms a gentle arch in the middle. Structurally, in the western part of Arkansas, these mountains are a broad, flat anticline, the strike of which is east and west. According to the geologists of the Arkansas Geological Survey, it appears that the extreme eastern part of the region is monoclinal in structure, with the dip to the south.[2]

With the exception of the Illinois River in the western part of the state, the drainage of the region is northward and eastward into White River, and southward into the Arkansas. The direction of the streams has been determined by the slopes incident to the uplift, modified in some cases by faulting and flexuring. The effect of the latter upon Little Red River and neighboring streams has already been noted by Professors Newsom and Branner.[3] The westward course of the Mulberry River has been determined by a fault. Detailed work of the region would doubtless disclose numerous other similar examples.

The drainage of the region is that intermediate between youth and maturity. The streams are vigorous, and have completely dissected the plateau by the formation of gorges from 500 to 1000 feet deep, thus producing a very rugged topography over the whole region. Between these gorges the slopes often meet, forming more or less rounded hills; but more frequently the intervening area is occupied by flat-topped, sandstone capped hills of limited extent.

The tributaries of both the Arkansas and the White rivers have worked their way back to, and in many cases, far beyond

[1] DR. N. F. DRAKE, in *Proc. of the Am. Phil. Soc.*, Vol. XXXVI, No. 156, p. 332.

[2] NEWSOM and BRANNER, "The Red River and Clinton monoclines, Arkansas," *Am. Geologist*, Vol. XX, July 1897, pp. 1–13.

R. A. F. PENROSE, JR., *Ark. Geolog. Surv.*, Vol. I, 1890; section with pocket map.

[3] *Loc. cit.*

the original water divide of the plateau, making the water divide as it now exists, a very zigzag line. In the western part of the state, the south-flowing streams are the stronger, and as a rule are robbing the White River basin of territory in this locality. Further east, in the middle portion of the region, the north-flowing streams are the stronger, and seem to be encroaching upon the drainage area of the Arkansas, while in the eastern part, the south-flowing streams head very near the north escarpment of the plateau.

The rocks of the region are mainly unmetamorphosed sandstones and shales, those at the base being of Lower Carboniferous age, and those at the top belonging to the Coal-measure series. These alternating hard and soft rocks have produced the terraces on the hill slopes, which are so characteristic of dissected regions of horizontal strata. As these terraces are often of considerable width, and are favorable horizons for springs, they are inviting to the farmer, and can be located miles away by the small farms on the mountain sides.

The low region to the north of the Boston Mountains is one of great denudation. From its northeastern part, all the rocks have been removed above the Ordovician, leaving those exposed at the surface. West and south of this is a region from which the Upper Carboniferous rocks have been removed, leaving those of Lower Carboniferous age at the surface. Standing up prominently on the latter are numerous hills of circumdenudation, composed of remnants of the horizontal strata of the Boston Mountains, and serving as living witnesses to their former extent. The height of these outliers very closely approximates that of the plateau of which they were formerly a part. This uniformity in height between the various parts of the dissected Boston plateau and its outliers suggests a peneplain, and herein lies the physiographic problem of the region.

In a region of folded or inclined strata the determination of a peneplain becomes a question of comparative ease, for in those cases denudation will have reduced both hard and soft strata to practically the same level, the peneplain intersecting

strata of all degrees of hardness. But in the case of horizontal strata undergoing base-leveling, the conditions are quite different, for then the peneplain conforms to the hard stratum or strata that happen to be near sea level. If such a region be subsequently elevated, the streams are revived, the region dissected, and the former peneplain represented by the tops of the hills, which would still be capped by the hard strata that were conformable with the peneplain before the region was elevated. Now this is exactly the structural and topographic conditions of the Boston Mountains and their outliers. But it happens that these are also the structural and topographic conditions that would prevail in a region of horizontal strata that has been elevated from beneath the ocean and is undergoing the process of base-leveling for the first time. So the problem presents itself as to which condition prevails in the Boston Mountains, and unfortunately criteria for its solution are largely if not wholly wanting.

Ordinarily, for the determination of a peneplain we look to the streams. In such cases, as is well known, the streams are winding, and flow in more or less steep-sided, symmetrical valleys, which are themselves cut down in wider valleys. In the Boston Mountains there is no such evidence of a peneplain. The streams of the region are all young, with the characteristic steep-sided gorges of such streams. So far as the writer has been able to observe, there is nothing in the region indicating an uplift since the present streams came into existence. Their valleys are relatively wide at their mouths, and gradually decrease in width back to their sources, as would be expected of streams cutting into a plateau of horizontal strata. The slopes are undisturbed by terraces, excepting such as those mentioned above, which are due to structure. Along the southern base, the oldest of the streams have reached the temporary base-level of the Arkansas River, and meander somewhat, but none of them to any great extent.

It follows that evidence of a former base-leveling, if there be such, must be looked for elsewhere than in the streams. A

recent writer[1] claims that the tops of the Boston Mountains represent a peneplain, and cites as evidence the fact that they correspond very closely in height with the Ouachita Mountains south of the Arkansas valley. This evidence is given on the assumption that the rather uniform height of these mountains represents a peneplain; but this is a hypothesis far from being established. Mr. L. S. Griswold, in his work on the novaculite region of Arkansas, encountered the problem of the nonconformance of some of the main streams of the region to the structure and topography, to account for which he presents the theory of a post-Carboniferous base-level, on which was subsequently deposited Cretaceous strata.[2] If the present writer correctly interprets Mr. Griswold, he believes the south-flowing streams, which form water-gaps in some of the highest mountains of the region, are superimposed streams, their courses having been determined by the slope of the Cretaceous area after elevation. Mr. Griswold does not claim that the evidence of this is conclusive. It is the opinion of the present writer, from somewhat limited observation, that the even crests of the Ouachita Mountains are due to structural and lithological conditions and not to base-leveling. But were it established that they represent a peneplain, the fact that the Boston Mountains closely agree with them in height does not argue a peneplain for the latter. The one is a folded area, and the other an area of horizontal rocks (Fig. 2). Erosion in the one has resulted in wide, anticlinal valleys through which flow sluggish streams, while erosion in the other is in its early stages. It would seem to follow that the time of elevation of the one region is far antecedent to that of the other, and consequently the correspondence in height between the two only accidental.

If, however, we look to the north of the Boston Mountains, we find conditions which seem to throw some light upon the subject. As has already been said, this is a region of great denudation. Its general elevation is from 700 to 1000 feet

[1] O. H. HERSHEY, *Am. Geologist*, Vol. XXVII, No. 1, pp. 25 *et seq.*

[2] *Ark. Geol. Surv.*, 1890, Vol. III, pp. 220.

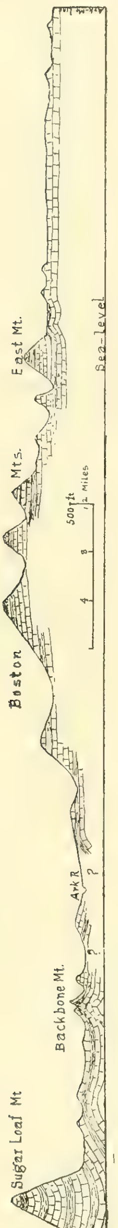

FIG. 2.—North-south section of the Boston Mountains and adjacent regions, near Arkansas-Indian Territory line.

lower than that of the Boston Mountains. Its streams are mature, the valleys comparatively wide, and the topography in general presents the aspect of much greater age than that of the Boston Mountains. Professor C. F. Marbut, in discussing that part of this region which lies in Missouri,[1] claims that it was base-leveled in early Tertiary times, and the present cycle of erosion was instituted by an elevation which dates from middle or late Tertiary times. Be that as it may, the question as to whether the region to the north of the Boston Mountains ever suffered denudation to the extent of base-leveling does not particularly concern us here. The fact of interest is that the denudation of the extensive region to the north has been very great and the topography is old, while that of the Boston Mountains is limited and the topography young.

It would appear that this difference in topography cannot be attributed to the massive beds of sandstone at the top of the Boston Mountains, for these same beds, while they have doubtless had a great deal to do with preserving the region, formerly extended over much if not all the denudated area to the north. Besides, if we attribute the preservation of these mountains to the character of the rocks composing them, we are encountered by the question as to why erosion has been so extensive to the north of the region, removing the rocks over a large area, leaving only here and there hills or circumdenudation, while in the southern part adjacent to the Arkansas valley it has scarcely begun.

I am able to account for the great difference in the stages of erosion in the two regions only by conceiving the Boston Mountain area to have been at a lower elevation than the area to the north during

[1] *Mo. Geol. Surv.*, Vol. X, pp. 27–29.

the time the extensive denudation was going on over the latter. So low must it have stood that the strata now composing their summits suffered but little erosion, while the same beds extending northward suffered much because of their greater height. If this be true, the actual amount of degradation suffered by the Boston Mountain region is indeterminable; but as there was more or less of it, and the region stood at a low level, it would be considered a peneplain. The elevation, which must have occurred in late Tertiary or in post-Tertiary time, was greatest along the present east-west axis of the plateau, gradually decreasing to the northward, and changing the region from a low, monotonous plain to a plateau approximating 2,500 feet in height, greatly modifying the former drainage and instituting that of the present.

Aside from the difference in topography between the region under discussion and the one to the north, the writer cannot at present claim very great support for the idea herein presented. There are, however, some other facts that seem to lend the hypothesis support. (1) The region being on the border of the Ozark uplift, it is probable that during the greater part of its history it lay at a low level and consequently suffered comparatively little from erosion. (2) The outliers of the Boston Mountains to the north are as a rule lower than the main plateau, though capped by the same rocks, thus indicating an axis of elevation to the south of the outliers. (3) The eastward course of White River and its tributaries may be due to their having been diverted from what would seem a more natural southern course, at the time of the uplift.

A. H. Purdue.

University of Arkansas,
Fayetteville, Ark.

THE DISCOVERY OF A NEW FOSSIL TAPIR IN OREGON

A FAIRLY complete phylogenetic series of early Miocene tapirs has been made known to science through the researches of Messrs. Wortman,[1] Earle, and Hatcher.[2] Between these ancestral forms, referable to the genus *Protapirus*, and the living species is a gap in the line of descent which has remained unbridged until the fortunate discovery of the form presently to be described.

Our knowledge of the tapir phylum since the White River epoch may be summarized in a few words. In 1873, Dr. Joseph Leidy[3] described under the name *Lophiodon oregonensis*, two imperfect superior molars obtained by Professor Thomas Condon at Bridge Creek, Oregon. Two species have been described by Professor Marsh,[4] which he refers to the genus *Tapiravus: T. rarus* from the Loup Fork of the Rocky Mountains, and *Tapiravus validus* from the Miocene of New Jersey. From the brevity of the description and the lack of figures, these species are practically indeterminate. Remains of tapirs belonging to the existing genus are known from the Quaternary gravels of California,[5] and have been described from several localities in the eastern states.

During the summer of 1900, Professor John C. Merriam and Mr. V. C. Osmont, of the University of California, while collecting in the fossil beds of the John Day valley, Oregon, obtained

[1] J. L. WORTMAN and C. EARLE, "Ancestors of the Tapir from the Lower Miocene of Dakota," *Bull. Am. Mus. Nat. Hist.*, Vol. V, p. 159.

[2] J. B. HATCHER, "Recent and Fossil Tapirs," *Am. Jour. Sci.*, 4th ser., Vol. I, p. 161, 1896.

[3] U. S. Geol. Surv. of the Territories, Vol. I, p. 219, Pl. II, Fig. 1.

[4] O. C. MARSH, *Am. Jour. Sci.*, Vol. XIV, p. 252, 1877.

[5] J. D. WHITNEY, "Aurif. Gravels," *Mem. Mus. Comp. Zoöl.*, Harvard, Vol. VI, p. 250; W. P. BLAKE, *Am. Jour. Sci.* Vol. XLV, p. 381.

the bones which form the subject of the following discussion. The remains are from the Promerycochœrus horizon (Upper John Day) exposed on the bank of the John Day river, beneath the Columbia basalt, to the west of Spray post-office, Wheeler county, Oregon. In a recent paper,[1] Professor Merriam named the beds of the Upper John Day the Paracotylops beds, basing the name on the new genus *Paracotylops*, proposed in the same paper by Dr. W. D. Matthew for the typical Oreodonts of this horizon. In the numbers of the *American Journal of Science* for last December and January, a paper by Mr. E. Douglass appeared in which these Oreodonts were provisionally named *Promerycochœrus*. Neither Professor Merriam nor Dr. Matthew read this article before the publication of Professor Merriam's paper, and consequently did not notice the new name. It now appears that *Promerycochœrus* should be retained as a generic name, and consequently, at Professor Merriam's suggestion, the name of the beds of the upper division has been changed from Paracotylops to Promerycochœrus beds.

The type specimen (No. M 934, Univ. of Cal. Pal. Mus.) comprises several superior incisors; the lower jaw lacking the posterior portion, with representatives of all the inferior dentition excepting the canines and the third molar; the proximal portion of the left humerus; the left radius; the scaphoid, lunar, magnum, and unciform of the right carpus; three metacarpals of the same side, and a few phalanges. The bones are those of a single individual of a new species of the genus *Protapirus*, for which the name *Protapirus robustus* is proposed. It is considerably larger than any of the White River species of *Protapirus*, and would approximate in size the most specialized living tapir, *Elasmognathus bairdii*. The lower jaw is represented about one-half natural size in Fig. 1. The symphysial region was found in place, imbedded in a buff colored tuff so characteristic of the Upper John Day beds that the expression "buff beds" was used as a convenient field term for this horizon. The other bones lay loose on the surface in the immediate vicinity.

[1] "A Contribution to the Geology of the John Day Basin," *Bull. Dept. Geol., U. of Cal.*, Vol. II, No. 9, p. 296; JOUR. GEOL., Jan.-Feb., 1901, p. 72.

The dentition.—The superior incisors are larger than the corresponding teeth in *Elasmognathus bairdii*. The inferior incisors are slightly smaller than the superior. Both series have the crowns somewhat cupped, especially so in the superior incisors. The first and second inferior incisors are of equal size, while the third is two-thirds as large as those preceding it. The crowns of both canines are broken off, but the diameters of their roots, measured on the alveolar borders, are greater than the corresponding parts of the larger incisors. A long diastema succeeds the canines. The premolars have their anterior cusps united into transverse ridges, slightly notched at the summit. In all

FIG. 1.

except the second premolar, the ridges are perpendicular to the long axis of the jaw. They are equally developed on the third and fourth premolars. Posterior cross crests are not developed on any of the premolars. In the second premolar, the protoconid is larger than the deuteroconid and is situated farther forward than the latter. In the succeeding premolars, these cusps are of the same size and are situated directly opposite each other. The tetartoconid of the premolars is smaller than the metaconid. The latter cusp is united with the inner side of the base of the protoconid by a ridge. This structure is also found in the molars, all of which have two cross crests. The posterior crest in the first and second molars is somewhat oblique to the axis of the jaw. The third molar is too imperfectly preserved to describe. Anterior and posterior cingula are present on all the molars and premolars. Traces of an external cingulum are found at the outer end of the transverse valley in all except the second premolar. In this tooth the paraconid is very large, uniting by a ridge with the protoconid. In the remaining premolars the paraconid is replaced by a style rising but little above the level of the anterior cingulum.

The jaw.—The inferior border of the jaw is parallel with the alveolar border. The symphysial portion rises at a low angle, much less than in the tapir. The flatness of this angle is perhaps due in part to a slight amount of crushing which the specimen has sustained. The posterior border of the mental foramen is directly below the anterior border of the second premolar.

The fore limb.—The humerus and radius have about the same shape as in the tapir. The deltoid ridge of the former is broken off, so that it is impossible to say whether it was hooked or not. The shaft of the radius is more strongly curved than the corresponding element in *Protapirus validus* as figured by Hatcher,[1] but a part of the curvature may be due to distortion. The carpus does not call for special description, not differing materially from that of *Protapirus obliquidens.* W. & E. The anterior contact of the lunar and magnum is still small, as in the White River species. There were four digits in the manus, the length of metacarpals III, IV, and V being about the same as in *E. bairdii*, but less robust. In shape they correspond closely with the metacarpals of the latter, except that the proximal portion of the fifth is inclined at a greater angle to the shaft of the bone than in the living form. The phalanges, which are of the second row, are shorter and less robust than those of the tapir.

Phylogenetic position.—The remains just described indicate an animal much larger than any of the White River species of the same genus. The structure of the molars and premolars suggests *Protapirus validus* as a probable ancestor. There are, however, several differences. In addition to the considerable difference in size, the third premolar of *P. robustus* has the anterior cross crest vertical to the long axis of the jaw, while in *P. validus* it is somewhat oblique. The diastema, as in *P. validus*, is shorter than in *Elasmognathus*, while the mental foramen has moved slightly posterior to the position it occupies in the White River ancestor. Gradations between the two types probably occur among the as yet unknown tapirs of the Lower and Middle John Day.

[1] *Loc. cit.*, p. 167, Fig. 1.

MEASUREMENTS OF PROTAPIRUS ROBUSTUS

Length of inferior molar-premolar series	128 to 130^{mm}
Length of inferior premolar series	60
Length of inferior molar series (approximate)	70
Length of diastema	46
Length of symphysis measured on lower side	71
Depth of ramus below alveolus of Pm. 2	48
Depth of ramus below alveolus of Pm. 4	49
Depth of ramus below alveolus of M. 3	43+
Length of radius	181
Breadth of proximal end of radius	45
Breadth of distal end of radius	39

In this connection, may be mentioned a second specimen, (No. M 1525 University of California Pal. Museum), representing probably another new species, obtained by the writer in the uppermost beds of the John Day system, on Johnson Creek, Grant county, Oregon. The horizon is considerably higher than that from which *Protapirus robustus* was obtained, and appears to be faunally distinct. It is characterized by the remains of numerous individuals of a camel belonging to the genus *Protomeryx* and by a rodent generically new. The tapir remains are of a young animal and are not complete enough to characterize specifically. They comprise fragments of a jaw with which three incisors and the second inferior premolar are preserved. The two large incisors, apparently the inferior median pair, are two-thirds as large as the corresponding teeth in *P. robustus*. They are spatulate in shape and slightly cupped. The anterior face is marked by delicate growth lines. The third incisor is an exceedingly small tooth with the crown $3\frac{1}{2}^{mm}$ broad. Imperfect preservation of the symphysial region renders it impossible to make any statement regarding the canine. The second premolar of the right side is the only one of the cheek teeth perfectly preserved. This tooth is entirely unworn, and was just appearing through the gums at the time of the animal's death. In this tooth, the tetartoconid is much larger than in *P. robustus* and the junction of the metaconid with the tetartoconid is much more complete, forming a cross crest but slightly notched. A ridge

joins the former cusp with the middle of the anterior cross crest. The protoconid is considerably anterior to the deuteroconid and as in *P. robustus* is united with the paraconid by a ridge. The anterior cross crest is sharply notched, but this structure would probably assume the character of the anterior cross crest in *P. robustus* with the wearing down of the deuterocone by use. External cingula appear at the outer margin of the median valley and on the external side of the paraconid. A posterior cingulum is also developed.

MEASUREMENTS

Width of the crown of first inferior incisor - - - - - -	$9\frac{1}{2}$ mm
Width of the crown of third inferior incisor - - - - - -	$3\frac{1}{2}$
Length of the first premolar crown, antero-posteriorly - - -	$15\frac{1}{2}$

WM. J. SINCLAIR.

PALÆONTOLOGICAL LABORATORY,
University of California.

THE FORMATION AS THE BASIS FOR GEOLOGIC MAPPING

In a recent number of this Journal Mr. Bailey Willis, in a paper on "Individuals of Stratigraphic Classification," has restated and rediscussed the problem which must be solved before cartographic work of any magnitude can be planned. This problem involves a careful consideration of the relative weights to be assigned, in any system of classification to be used on geologic maps, to faunal, lithologic, and chronologic (successional) characters. Mr. Willis discusses the question in its various aspects, and his final decision is that the lithologic unit (formation) is best adapted to the requirements of the cartographer.

While agreeing, in the main, with the conclusions reached by Mr. Willis, it seems desirable to call attention to certain arguments, not specifically mentioned by him, which may be adduced in support of those conclusions; and, further, to examine the results of the application of the proposed system of classification to some particular cases of interest.

Before commencing the discussion of this question I wish to acknowledge my indebtedness to Dr. F. J. H. Merrill, director of the New York State Museum, who has greatly aided me, with both criticism and advice, during the preparation of this paper.

THE NECESSITY FOR UNIFORMITY

Though the formation, defined primarily by lithologic characters, was officially adopted in 1889 as the cartographic unit of the United States Geological Survey, in practice it has not entirely superseded other units of classification. Great variety exists in the practice of the various state geological surveys, as is indicated by their official maps; and greater variety, as might indeed be expected, in unofficial maps accompanying papers on

areal geology, even though the authors be connected with surveys whose official practice is uniform.

In considering the representation on a map of the geological features of a small, isolated area, the question of the taxonomic unit to be employed is usually of minor importance; though even in this case, as shown later, there would seem to be good reasons for the adoption of the lithologic individual as this unit. The interest attaching to this question increases directly with the size of the area to be mapped; and the problem becomes of paramount importance when the independent work of several geologists is to be combined, as in the compilation of a geologic map of an entire state or other large area.

In view of these facts, and of the slow but steady spread of the geologic-folio work carried on by the United States Geological Survey, it would seem necessary that the various local surveys should adopt the same general system of classification for map work. In the present state of our knowledge, detailed chronologic classification, the unit for which would be the epoch[1] of earth-history, is impossible; and the problem of unification is therefore resolved into the choice between two alternative systems, based respectively upon biologic and lithologic characters. In the opinion of the writer a geologic survey, whether state or national, can best accomplish the work for which it is intended by adopting as its cartographic and taxonomic unit the formation, defined as a lithologic individual.

THE RELATIVE SCIENTIFIC VALUES OF BIOLOGIC AND LITHOLOGIC UNITS

For the purposes of the present discussion it is necessary to point out that our knowledge of the two histories (*i. e.*, of sedimentation and of life), so far as that knowledge can be expressed on maps, is decidedly different in grade. The present phase of earth-history may be examined for a determination of the truth of this statement. We can map without difficulty the topographic features of the earth; and the possible accuracy and

[1] The word epoch is here used in an entirely general sense.

precision of such mapping is limited only by the consideration of expense. Moreover, we are able in most cases to discuss topographic features in terms of causality.

With regard to the present biologic condition of the earth our knowledge is much less definite. Mapping the distribution of existing faunas or floras is not practicable in the present state of our knowledge of biotic[1] distribution, except in a very general way; anything like a detailed map is impossible. This condition is due partly to the expense of collecting sufficient data on the range of the different species of plants and animals. Most of the difficulty, however, arises from the fact that the principles underlying and regulating animal and plant distribution are still far from being well understood, though of late years great advances have been made in that direction.

If our knowledge is thus imperfect with regard to the existing biota,[1] our knowledge of the facts and causes of its distribution during past ages is still less definite. It is noteworthy that two of the most successful attempts[2] to account for biotic distribution and evolution in periods antedating the present have been the work of geologists specializing in physiographic work, a branch which necessitates lithologic rather than biologic discriminations.

Obviously, the paleontologic record must always be more defective than the lithologic; for fossils are not always found where rocks are exposed. In addition to gaps occurring because of local lack of fossils, two periods are particularly incapable of being treated on a biologic basis; one immensely long period at the commencement of geologic history, and one short but highly important period immediately preceding the beginning of written history.

With regard to the relative values of the biologic and lithologic units as measures of absolute time, the case is somewhat

[1] Biota = the sum of the fauna and flora of a region. *Cf.* STEJNEGER, *American Naturalist*, February 1901, p. 89.

[2] T. C. CHAMBERLIN, "Systematic Source of Evolution of Provincial Faunas," JOURN. GEOL., VI, pp. 597–608, 1898. J. B. WOODWORTH, "Relation between Base-leveling and Organic Evolution," *American Geologist*, XIV, pp. 209–235, 1894.

in favor of the latter unit; for the relation existing between time taken in deposition and thickness of formation is much more traceable than that between extent of variation and time taken in evolution.

In considering the adoption of a basis for geologic mapping the biologic unit has, therefore, no antecedent claim to special consideration on scientific grounds; and its value can be compared directly with that of the lithologic unit in regard to their relative practicability and utility.

THE RELATIVE PRACTICABILITY OF THE TWO SYSTEMS

A lithologic unit can usually be so described and defined as to be readily identified by any future worker in the same or an adjoining area through which the formation extends.

It should also be noted that all geologists substantially agree upon the use of the terms in which lithologic individuals are defined, and will consequently agree closely in their valuation of any series. "Limestone," "sandstone," "slate," "conglomerate," all have fairly definite meanings, and it is improbable that terms such as these are used in very different senses by different geologists. The biologic unit, on the other hand, is rarely capable of being so described or defined as to be acceptable to all paleontologists. The difference is that the lithologic individual is a fact; the biotic individual, as commonly described, is a fact plus an interpretation; and while there may be substantial agreement as to the facts in any given case, it is but rarely that the interpretations will coincide.

The Hudson formation in the vicinity of Albany, N. Y., presents an excellent example of some of the practical difficulties encountered in attempting to represent faunal distinctions on a map; and a brief sketch of the conditions may be of interest in the present connection.

The "Hudson River group" of the earlier classifications—the "Hudson formation" of the present system of nomenclature—comprises in the central portion of the Hudson River valley, where it is best developed and exhibited, a thick and extensive

series of shales, with interbedded sandstones and occasional thin beds or lenses of limestone. This series is well shown along the banks of the Hudson River, extending almost uninterruptedly from Fort Edward to Cornwall. Faunal differences justify the paleontological division of the "group" into four stages, of which the two lower carry a fauna which would correlate them with the Trenton (using that term in its paleontological significance), while the other two represent respectively the Utica and Lorraine beds of the Mohawk valley. This division into stages, however, is and must be largely theoretical, for it cannot well be carried out in practice on a map. Fossils, especially of species which can be regarded as of taxonomic importance, are neither profusely nor regularly distributed throughout the beds in question. Outcrops carrying characteristic fossils are too few and far between to warrant mapping the area, on a paleontological basis, on any large scale. The lithologic differences which occur in the group have no stratigraphic or cartographic value, being too slight and variable to admit of separate representation on a map.

Modern geologic mapping, especially if the base of the map is to be a topographic atlas sheet, in order to make adequate returns for the expense involved, must be accurate within the limit fixed by the scale of the map.

The production of a geologic map is necessarily accomplished by the exercise of two functions, observation and inference. Observation involves the location of outcrops and lithologic boundaries with reference to fixed points in the control of the map, and is therefore purely a matter of engineering. The exercise of the function of inference is necessary in order to indicate the positions of boundaries concealed by superficial material. Inferences in relation to such matters are dependent for their accuracy on the training and judgment of the geologist; his appreciation of the relations existing between structure and topography, and his knowledge of the geometric effects of dip, pitch, etc., in determining the position, both horizontal and vertical, of a concealed boundary line.

Other things being equal, the determination of the altitude and geographic position of a given point is dependent upon the engineering skill of the observer; and the cartographic unit to be employed does not seriously affect this phase of the work of mapping. With regard to inference, however, this is not the case. No necessary relation exists between a biologic unit and the topography or structure of the area in which it occurs. On the other hand, topography, structure, and the lithologic unit are in general closely related. Recognition of these relations makes it possible to draw inferences concerning the position of the concealed boundary of a lithologic unit from the geologic structure and topography of the area discussed.

THE RELATIVE UTILITY OF LITHOLOGIC AND BIOLOGIC MAPS

A lithologic unit is normally also an economic unit, whereas there is no necessary relation between the biologic unit and the economic importance, or lack of importance, of the rocks containing a given biota. Though this argument may be regarded by some as of less weight than one based on purely scientific grounds, it is nevertheless valid, as applied to the question under discussion. It should not be forgotten that no geologic survey has ever been instituted, save for economic reasons; that the chief argument that can be used to obtain state support for such surveys is the direct economic return to the public; and that simple justice demands, in return for this support, that the geologic results obtained be placed in such a form as to be of the greatest possible use to that public.

The lithologic unit is also generally related to geographic forms in a very definite manner, as well as to geologic structure. The effects of these relations upon the actual work of mapping have been discussed. Here it is only necessary to point out that both topography and structure are often of economic importance. A map based on a unit which bears some definite relation to them is, therefore, of greater value from an economic standpoint than if the unit be one not so related.

THE DIFFICULTIES IN MAPPING ON THE LITHOLOGIC BASIS

Difficulties will certainly be encountered in mapping any large area on a lithologic basis, but these difficulties will arise rather from differences in the interpretation of the rules for the nomenclature of the units than from any defects in the system itself. Certain cases of interest in this connection are discussed below:

Case 1.—The case is that cited first by Mr. Willis (p. 563). A shale passes along the strike into a limestone which retains identical stratigraphic associations. "Being exactly continuous stratigraphic units, they should retain the same geographic name on grounds of convenience and simplicity." Considered as a stratigraphic unit, the two would be discussed as the "X" formation. In order to preserve all the advantages of the lithologic system of classification, however, the limestone phase should be differentiated, in both discussion and mapping, from the shale phase; their respective names being then the "X" limestone and the "X" shale. The term "phase" seems to serve a useful purpose in this connection, and the present writer, therefore, proposes it for use in marking variations of sedimentation or of metamorphism within the stratigraphic unit. When used later in this paper, it will be with this restricted and definite meaning.

This case is illustrated excellently in New York state and western New England, in this example the phases representing variations in metamorphism. The Hudson shales of the central part of New York state are progressively metamorphosed to the eastward, becoming first slates and then mica-schists. The schistose phase has been called, in Massachusetts, the "Berkshire schist;" in southeastern New York, by Merrill, the "Manhattan schist," while Dale has described the intermediate phases as "Hudson slates." Throughout the entire area, though differing thus in character because of variations in metamorphic action, the rocks are essentially continuous stratigraphically; and recognition of this fact has led to the recent proposition to eliminate the names Berkshire and Manhattan, and denote the

various phases of the Hudson formation by the term "Hudson shale," "Hudson slate," "Hudson schist." This system of nomenclature, while recognizing the essential stratigrapic equivalence and continuity of the various phases, allows these phases to be discriminated from each other on lithologic grounds. On maps this discrimination can best be shown by the use of some of the various overprints used to denote metamorphism.

Case 2.—The second case noted by Mrs. Willis is that of a "shale grading into a limestone with prolonged overlap, so that the two rocks must be discriminated in one area. Not only are they lithologically different but they have different stratigraphic associations, and they should receive distinct" formational names. As noted under the preceding case, this is the condition which usually obtains where there is a horizontal gradation in character of sedimentation. The writer believes that Mr. Willis has here suggested the proper treatment of the question, but wishes to point out an actual case of some areal importance in which this ruling has not been followed.

The example occurs in the northwestern part of Massachusetts. To the west of Hoosac Mountain, the Cambrian quartzite is overlaid by Stockbridge limestone and this in turn by Hudson (Berkshire) schist; on and east of the mountain the limestone does not appear. It has been generally assumed that the schist of the mountain represented both the Berkshire schist and the Stockbridge limestone, and the name "Hoosac schist" has been applied to it in several publications.

What the writer wishes to point out is that, under the proposed rules, the name at present used for one of those formations would seem to be untenable. For, if the eastern (Hoosac) schist represents both the Berkshire schist and Stockbridge limestone, the case becomes the same as 2, and in that case all the schist should be called Berkshire and all the limestone Stockbridge. If the transition be considered sudden, then it exhibits a slight modification of case 3, and still all the schist is Berkshire schist and all the limestone Stockbridge limestone. If the relations at Hoosac Mountain be referable to overlap,

then it is obvious that the Hoosac schist is simply an equivalent of the Berkshire schist, while none of the Stockbridge limestone is represented by any of the schist east of the mountain. On any hypothesis, therefore, the formation name "Hoosac schist" is apparently untenable.

Case 3.—The third example cited by Mr. Willis is that of a shale which varies horizontally in such a manner as to become differentiated into several superposed members, one of which is a similar shale, the others limestone or sandstone. His decision is that in such a case all the shale can be given the same formation name, while the new members (limestone, sandstone, etc.), are to be given distinctive names; but that, in case it be desirable to refer to the group as a whole in some area where it is thus differentiated into several members, the geographic name applied to the shale alone cannot be applied to the entire group.

The last three cases cited by Mr. Willis present instances of subordinate parts or local developments (of the lithologic unit) which, though too small for mapping, are of interest in discussion. To such sections of the unit the terms "member" or "lens" may be applied. This method of treatment and terminology, if followed strictly and uniformly, would seem to be entirely satisfactory.

SUMMARY.

It will be seen that the essential character of the proposed unit is that it is uniform, or uniformly variable, in lithologic character. Both its upper and lower limits and its lateral boundaries will therefore by marked by lithologic differences. So long as the formation is geographically continuous, no other criterion is necessary or even admissible.

In the case of discontinuities in outcrop, caused by the presence of bodies of water, or of intervening areas of other rocks or superficial deposits, the question will arise as to the treatment in mapping of two distinct bodies of rock, identical lithologically. In this case the aid of stratigraphic association or contained fossils may be invoked.

In regard to sharpness of definition, ease and accuracy of

mapping, and utility of the resulting maps, the lithologic unit would seem to leave little to be desired. Difficulties arising from diverse interpretations of the rules for its discrimination can be overcome with little trouble. A more serious difficulty, however, is to be encountered in regard to the question of the geographic names to be given the units. It is not sufficient to say that the rules of priority will determine the name to be used, even if those rules be re-formulated with special regard to this particular question. The difficulty to which the writer alludes can almost be said to be inherent in the definition of the unit and to be avoidable only by giving a very free interpretation of that definition. It arises when two or more geologists, who commenced work in more or less widely separated areas, have carried areal mapping to a junction. Identical formations will then bear different names on adjoining folios. In regions whose geology is fairly well known, identity of nomenclature can generally be arranged in advance with safety. In less well-known regions, however, the possibility that the same formation may require treatment under different names in adjoining folios will have to be accepted as a necessary evil, largely outweighed by the positive advantages of adopting the lithologic unit as the basis for mapping.

EDWIN C. ECKEL.

NEW YORK STATE MUSEUM,
Albany, N. Y.

GLACIAL WORK IN THE WESTERN MOUNTAINS IN 1901.[1]

During the season of 1901 some time was given to the study of Pleistocene problems in the western mountains. Four small parties, beside the writer, were in the field. The work of three of the four parties was the somewhat detailed study of selected areas, and was intended to make known the general conditions of glaciation at several somewhat widely separated localities. When a sufficient number of selected areas have been studied similarly, the results will afford a basis for preliminary conclusions concerning the course of Pleistocene history in the western mountains, and will be helpful in guiding future work. The work of this summer was intended as the beginning of study looking to this end.

The writer spent about six weeks in the region, mostly in association with the parties referred to. One party was in northwestern Montana, east of the Rockies; one farther west, on the western side of the Rockies, in northwestern Montana, northern Idaho, and eastern Washington; one in the Wasatch Mountains; and one in the mountains of New Mexico, a few miles northeast of Santa Fé.

The following brief summary will give some idea of the work done:

NORTHWESTERN MONTANA, EAST OF THE ROCKIES.

Mr. Fred H. H. Calhoun, accompanied by Mr. Bruce McLeish, spent three months in the northwestern part of Montana. The area studied, some 8000 square miles in extent, lies just south of the 49th parallel, and just east of the Rocky Mountains. It is the area in the angle between the Continental ice sheet from the northeast, on the one hand, and the Cordilleran ice sheet from the northwest, and the mountain glaciers from the west, on the other.

[1] Published by permission of the Director of the U. S. Geological Survey.

The moraine formed by the northeastern ice sheet of the Wisconsin epoch was traced from Fort Benton, *via* Choteau, to the point where it crosses the 49th parallel, about longitude 112° 20′. From this point the moraine bends to the west and continues in this direction to the Watertown River, where it turns to the north, its course being nearly parallel to the mountains.

The moraines of fourteen glaciers from the Rocky Mountains were mapped. The recessional moraines of both the valley and continental ice masses were studied as far as time permitted. Study was also made of the extent of valley trains and outwash plains, and of the lakes which existed in front of the ice during the glacial period.

Among the results of the work, the following may be mentioned:

1. The westward and southwestward extension of the Wisconsin drift is greater than had been supposed.

2. The till of the northeastern ice sheet and that of the mountain glaciers overlap just south of the 49th parallel, between the meridians of 113° 10′ and 113° 15′. At no other point south of the boundary line did the ice from opposite directions occupy the same territory; but in Two Medicine Valley (latitude 48° 30′) the ice from the east advanced to within two miles of the position occupied at an earlier time by the ice from the mountains.

3. The ice sheet from the northeast reached its most advanced position after the valley glaciers from the west had retreated, for the drift of the former overlies the drift of the latter at various points, both north and south of the national boundary. In some cases the till from the northeast overlies the till from the west. This is true in the locality mentioned under 2, and farther north in the valleys of St. Mary's River, Belly River, and Lees Creek. In other places the till from the east overlies fluviatile deposits connected with the western drift, but extending down the valleys some miles beyond (east of) the ends of the mountain glaciers. In still other cases lacustrine

and berg deposits, having their source in the northeastern ice, overlie the till laid down at an earlier time by the mountain glaciers.

4. The valley glaciers belonged to a recent epoch. They were certainly not earlier than the Iowa epoch, and probably as recent as the Wisconsin.

5. The drift of the northeastern ice sheet is of Wisconsin, possibly late Wisconsin age.

6. So far as the evidence gathered shows, the length of time which elapsed after the deposition of the Rocky Mountain drift, and before the deposition of the drift of the ice sheet from the northeast, was not great.

7. The time since the last glacial epoch, as shown by several lines of evidence in the area studied, seems to have been geologically short.

8. The Sweet Grass Hills, situated just south of the 49th parallel and about thirty miles back from the edge of the ice sheet from the northeast, were not covered by the ice. The hills stood as three great nunataks, the highest reaching about 2000 feet above the surface of the ice.

9. The slope of the surface of the continental ice sheet between its edge and a point 25 miles back from its edge was estimated at about 50 feet per mile. This determination was made in the vicinity of the Sweet Grass Hills. The slope of the surface of the ice in various valleys was also determined.

10. The existence of a long narrow lake in front of the edge of the Continental ice sheet, and between it and the mountains, was proved, and its extent determined.

11. Considerable changes in drainage were effected by the ice. Some data were gathered which throw light on the former courses of the Missouri, the Teton, and the Two Medicine rivers, and of Buck, Muddy, and Cut Bank creeks.

Besides these conclusions touching glacial problems, some other observations were made:

12. The region studied shows at least three periods of erosion, when the land stood at different levels.

13. The high-level quartzite gravels on the plains east of the mountains are believed to be deposits made by streams at the close of the first epoch of base-leveling recorded in the present topography.

14. The strata at the mouth of Sun River and Muddy Creek canyons contain fossils of Carboniferous age. Rocks of the same age prevail in the whole of the eastern face of the mountains, where their thickness is several thousand feet.

Some other scattering data were collected touching the general geology of the region studied.

BETWEEN THE ROCKIES AND THE CASCADES IN NORTHWESTERN MONTANA, NORTHERN IDAHO, AND EASTERN WASHINGTON

Messrs. George H. Garrey and Eliot Blackwelder spent most of August and September in the study of glacial phenomena in northwestern Montana, northern Idaho, and northeastern Washington, most of the time being spent in the latter state, between Chelan Falls and Newport. The moraine of the ice lobe which came south through the Okanogan Valley, loops southeastward from Chelan Falls to a point about six miles west of Coulee City, where it bends northeastward to a point five miles north of the city, on the bluff of the Grand Coulee. Morainic material not aggregated into a marked terminal moraine, continues northward along the entire western rim of the Coulee. During glacial times the ice probably blocked the Columbia at its junction with the Grand Coulee, forcing the waters of the Columbia down the Coulee, as has been suggested by Russell and others. That glacial drainage followed the course indicated is suggested by the fact that the terraces of the Columbia above the Coulee are continuous with terraces in the Coulee.

Northeast of the junction of the Grand Coulee with the Columbia, the moraine of the Okanogan or Coulee City lobe takes the form of a well-developed ridge which, at a point about five miles north of the junction of the Columbia and the Grand Coulee, the most northerly point where it was seen, was trending

slightly to the west of north. After continuing northward for a distance, this moraine probably loops eastward around the mountains in the Colville Indian Reservation, connecting with the moraine of the ice lobe which occupied the Columbia valley, north of its junction with the Spokane. The Okanogan or Coulee City ice lobe was about thirty-five miles wide in the latitude of Chelan Falls, and nearly fifty miles wide at the upper end of the Grand Coulee.

The moraine of the ice lobe which came down the valley of the Columbia, just west of the meridian of 118°, was traced southward from a point in the Colville Indian Reservation about three miles west of Kettle Falls on the Columbia, to the point where it crosses the Columbia seven miles southwest of Fruitland. Between these points, the moraine lies three to six miles west of the Columbia. Just east of the Columbia the moraine is lost in the terraces at the junction of the Columbia and Spokane valleys. From this point the moraine was traced northeastward, passing about three miles east of Fruitland, and thence along the west face of the mountains, to the Huckleberry Mountain in the S. E. corner of Tp. 32, R. 38, E. (about latitude 48° 15′). At this point it loops around and over the northeastern end of this mountain, and then turns southward in the Colville River Valley. The glacier of the Columbia Valley had a width of about six and one-half miles in latitude 48°, and a width of about fifteen miles, fifteen miles farther north.

As already mentioned, the moraine of the Columbia glacier loops over and crosses Huckleberry Mountain and becomes continuous, in the Colville Valley, with a lobe of ice which descended that valley to Springdale. The moraine of the east side of this lobe was traced northward along the mountains east of the Colville Valley, to Old Dominion Mountain, seven miles east of Colville. This seems to be the latitude where the moraine swings across the mountains to the east, though the crossing was not demonstrated. The Colville glacier had a width of about thirteen miles at Valley, about eight miles north of the southern end of the lobe. The width of the combined Colville and

Columbia glaciers just north of their union (lat. 48° 15′ approximately), was about thirty-three miles.

In the Pend d'Oreille Valley there was another ice lobe, which extended down the valley to a point three miles southwest of Davis Lake. To the northwest this moraine is believed to connect with that of the Colville lobe, north of Old Dominion Mountain, though this connection was not established. The moraine of this lobe crosses the Pend d'Oreille River to the eastward at the great bend of the stream eight or ten miles above Newport. East of the Pend d'Oreille the moraine of the east side of this ice lobe was judged, on the basis of topography, to turn northward.

Another ice lobe came down the Kootenai Valley, but its southernmost limit was not determined. On the basis of data gathered at other times by Professor Chamberlin and the writer, the ice of the Kootenai Valley is believed to have extended to the southern boundary of Pend d'Oreille Lake. It is possible that the Kootenai lobe connected to the northwestward with the Pend d'Oreille lobe; but, if so, the connection is well to the north of Bonners Ferry, and probably north of the boundary line.

It remains to be determined whether the Okanogan, Columbia, Colville, Pend d'Oreille, and Kootenai glaciers were marginal lobes of a single continuous ice sheet, the body of which lay to the north, or whether some of them had separate sources in the mountains. The connection of the second and third of these lobes was established, and data at hand make the connection of the third and fourth seem probable. The connection of the first with second, and of the fifth with fourth, if such connection exists, is probably near the boundary if not beyond it. In any case, the glaciers partially traced out were large — quite beyond the Alpine class.

A few data concerning glaciation farther east were also gathered. General glaciation did not occur as far south as Newport at the east line of Washington. Above Libby (in the Kootenai Valley near the west line of Montana) there was gen-

eral glaciation from the north, though a few miles south of the river in this longitude drift from the north comes in contact with drift from the Cabinet Mountains. Whether the glaciation from opposite directions was contemporaneous, was not determined. Deposits of lacustrine clay some 300 feet thick in the valley near Libby, point to notable interruptions of drainage during glacial time, and probably to considerable changes since.

The Flathead valley contained a great glacier which advanced southward beyond the southern end of Flathead lake, though the southern limit of the ice was not traced out this season. In the latitude of Kalispell, the ice of this valley was about 3000 feet thick, as shown by the height to which the west face of the Kootenai Mountains east of the valley, was glaciated. The general direction of ice movement in this valley at Kalispell, and between this place and the lake, was south-southeast. The main body of the ice, therefore, came down the valley from the north northwest, and not from the mountains immediately east or northeast, though the main glacier was reënforced to some extent by ice from this direction. The source of ice which moved to the south-southeast was not determined. One lobe of the Flathead glacier moved southwest up the valley of Ashley Creek (the valley followed by the Great Northern Railway west of Kalispell), and another advanced westward a short distance beyond the end of the west arm of Flathead Lake.

The face of the Kootenai Mountains east of the Flathead Valley is abrupt, and not deeply indented. From the slight amount of study given to this face of the range, it would appear that local glaciation here was not of great extent or severity, for some of the considerable mountain ravines opening out to the west afford little evidence of glaciation. On the other hand, glaciation was severe in some of the valleys, as in that followed by the Great Northern Railway east of the Flathead Valley.

THE WASATCH MOUNTAINS.

Mr. Wallace W. Atwood spent about two months in the study of the glacial phenomena of the Wasatch Mountains. He was

accompanied and assisted by William Peterson, M. J. Averett, H. B. Atwood, and Arthur Church.

The portion of the Wasatch Mountains studied lies between the parallels of 40° 15′ and 41°. The maximum width of the range in this latitude is about twenty miles. The total area examined for glacial phenomena was about 1000 square miles.

Within this area, the positions of fifty Pleistocene glaciers exceeding a mile in length were determined. Traces of several smaller glaciers and of more than a dozen névé fields were also found and mapped. Of the fifty larger glaciers, seven reached the shore line of Lake Bonneville, and the moraines of at least three of them are clearly seen to be partially buried by the fluviatile deposits near the shore, or possibly by the shore deposits of the lake itself.

The elevation of a catchment basin necessary to give rise to a glacier in this region, was between 8000 and 9000 feet, and, except where the basins were very favorably situated, the latter figure is more nearly correct.

The crest line of the Wasatch Mountains is near the eastern border of the range. The valleys of the west slope are therefore much longer than those of the east, and the glaciers of the two slopes were, in a general way, of corresponding lengths. The number of ice tongues on the west was also much greater than on the east. Of the fifty glaciers over one mile in length, forty-six were west of the crest, and but four east of it. Of the ten glaciers which reach or exceeded five miles in length, nine moved westward and but one eastward. The Little Cottonwood glacier on the west slope was twelve miles long, while the greatest length reached by any glacier on the east slope was five miles. East of the crest, one glacier descended to an altitude as low as 6000 feet, and two others descended to 7000 feet. On the west slope fourteen glaciers descended to an altitude of less than 6000 feet, and seven to 5000 feet.

The greater number and size of glaciers on the west side of the range as compared with the east side, were determined by (1) the larger catchment basins, and (2) the heavier snowfall. A

third factor, of local importance, was the accumulation of snow in catchment basins among the lofty peaks of two east-west divides, lying west of the main crest. These basins, in many instances, furnished tributary glaciers to the main canyons, and thus greatly increased the amount and strength of the work done by the ice on the west side of the range.

Glaciation was not only more extensive, but also more vigorous on the west side of the range than on the east. This is shown by a more complete cleaning out of loose material from the glaciated valleys of the west slope, by the more complete reduction of their asperities of surface, by the greater deepening of the main canyons on this side, leaving their tributary valleys "hanging" 200 to 300 feet above, and by the development of more massive moraines. The moraines of the east-slope glaciers are insignificant in comparison with those of the west slope glaciers.

The work of the season removes all doubt as to the duality of the ice age in the Wasatch Mountains. There were at least two ice epochs separated by a long interglacial interval. Evidence of more than two epochs was not found. The basis for the above conclusion is as follows:

1. In several valleys there are outer moraines, much older than the inner moraines of the same valleys. A considerable tunnel exposure in one of these outer moraines showed essentially all of the abundant granite bowlders, up to four feet in diameter, so thoroughly disintegrated that they had been cut through with picks and shovels in the excavation of the tunnel. Most of them could be crumbled by the hand. This condition of things was not superficial, but held to the depth of twenty feet, the deepest point of exposure.

2. In certain glaciated canyons there are such variations in the amounts of postglacial change (weathering, erosion, etc.) which different portions of the drift and valley walls have suffered, that it seemed necessary to postulate much longer exposure for certain parts than for others. In all such cases, the drift which appears to be older, extends beyond that which

appears to be younger. The ice of the earlier epoch, therefore, seems to have been more extensive.

3. Two distinct sheets of drift were found at several points in the valleys of both the North and South Forks of the American Fork. These sheets of drift are separated by a soil twelve to eighteen inches thick. In the same localities, the soil on the surface of the upper drift sheet, formed since the last retreat of the ice, is from four to six inches thick. So far as the thickness of soil is a basis for estimating time, it would indicate that the interval between the ice epochs was longer than the time since the last.

The topography of the region examined was somewhat modified by glaciation. The valleys which were occupied by ice are usually U-shaped, and their slopes are commonly smoothed off as far up the sides as the ice reached. Such forms are in sharp contrast with the V-shaped canyons and rugged slopes of the valleys not occupied by ice. In some of the glaciated valleys massive moraines were built up. These are sometimes in the canyons, and sometimes at their débouchures, according to the position which the ends of the glaciers reached at the time of their maximum extension. When tributary glaciers joined the main, medial moraines were formed, and as the ice melted, these moraines were left as ridges, parallel with the course of the valley. Recessional moraines are frequently found crossing the valleys as crescentic ridges, convex down stream. These ridges often served as dams, above which lakes accumulated, rose, and overflowed. The outlet streams of such lakes cut gorges in the moraines. Near the heads of many valleys the ice gouged out rock basins, 50 to 200 feet in diameter and from 5 to 20 feet in depth. At least thirteen of the thirty-six glacial lakes mapped, are in rock basins apparently made by the ice.

The relation of the moraines at the west base of the Wasatch, to the fluviatile (or shore) deposits in the Bonneville basin, is such as to indicate, as Gilbert has pointed out, that the last advance of the ice from the mountains occurred during a late period in the history of Lake Bonneville. The close correlation

of the earlier ice epoch with the earlier wide extension of the Bonneville waters cannot as yet be asserted, although the data at hand strongly suggest the contemporaneity of the early expanded stage of Lake Bonneville and the early glaciation.

THE MOUNTAINS NEAR SANTA FÉ

Messrs. John E. Webb and William A. Averill spent about one month in the mountains of New Mexico, a few miles northeast of Santa Fé. The area studied was the Santa Fé range of the Rockies, which traverses the northeastern portion of New Mexico, running in a general north-northeast, south-southwest direction through the adjacent parts of Santa Fé, Rio Arraba, Mora, and San Miguel counties, between the parallels of 35° 45′ and 36°, and the meridians of 105° 35′ and 105° 50′. The aggregate area comprises about 250 square miles.

The height of the range in the area studied varies from 7000 feet to 13,306, feet, the latter being the altitude of the highest of the Truchas peaks. The altitude which seems to have been necessary for the generation of glaciers was 11,700 to 12,000 feet. The following peaks attained the requisite height: Lake peak, 12,380 feet; Baldy peak, 12,623 feet; Pecos Baldy (Cone peak?), 12,550 feet; Jicarilla peak, 12,944 feet; and the Truchas group, the highest peak of which is 13,306 feet. Clear evidence of glaciation was not seen on lower peaks, though it cannot be said that many of the lower peaks were studied in the detail necessary to demonstrate the complete absence of glaciation.

Heading against these peaks and their connecting ridges, fifty cirques bearing evidences of glaciation were observed. Névé fields, with incipient motion, existed at some points where well-formed glaciers did not develop. Sixteen of the cirques are in the group of mountains (Lake, Baldy, and associated ridges) at the head of Santa Fé Creek; seven in the Pecos Baldy group; twelve among the Truchas peaks; and fifteen about Jicarilla peak, and the ridge between it and the Truchas peaks. Of these cirques, twenty-five open toward the east, thirteen

toward the north, seven toward the south, and five toward the west. The cirques range from one-fourth of a mile to two miles in width, and from one-eighth of a mile to two and one-half miles in length, and from 150 to 1000 feet in depth. Most of them contain lakes or ponds, some of them as many as six, and almost all contain flats or bogs, indicating the former existence of standing water, where there is none now. The total number of ponds and lakelets seen was about eighty. Since they were seen in the rainy season, the number of permanent bodies of standing water may be less.

The longest glacier track studied is in the valley of the Santa Fé Creek. The ice emanating from three cirques united to form a single glacier which Messrs. Webb and Averill think extended some seven miles down the valley, its lower end reaching down to an altitude of about 9200 feet, the lowest altitude, so far as seen, to which the ice descended. The largest area of glaciation from a single source is that on the east side of the Pecos Baldy group, in the valley of Jack's Creek, while the largest continuous area of glaciation (to which the ice from several sources contributed) is that along the group of mountains at the head of Santa Fé Creek.

The moraine matter left in the cirques, and in the valleys below them, often has a pronounced hummock-and-hollow topography. Its composition varies from point to point. The chief accumulations are in the bottoms of the valleys. The morainic matter is often disposed in ridges most commonly roughly parallel to the axes of the valleys and to the direction of ice movement, but often oblique or even at right angles to this direction.

Striæ were found on *roches moutonneés* in several places, while smoothed and polished rock surfaces are of frequent occurrence.

The higher ridges and peaks of the glaciated regions are serrate, but serrate crests are confined strictly to the higher parts of the range. Serration often characterizes the tops of the mountains, on the sides of which the glaciated cirques lie.

OTHER OBSERVATIONS

In addition to the foregoing work, some further data were gathered at several points, touching Pleistocene geology in the West. It was found that loess has somewhat extensive development in eastern Washington and northeastern Oregon, though its limits were not determined. It is widespread in Douglas, Lincoln, Whitman, Columbia, Walla Walla and probably Spokane counties, Washington. It is very generally distributed over the northern part of Umatilla county, Oregon. In geographic distribution it seems to correspond, in a general way, with the great wheat belt of the states mentioned. In topographic distribution, it has the general habit of the corresponding formation in the Mississippi basin; that is, it has a preference for considerable elevations. So far as seen, however, its disposition to follow streams is less pronounced than in the Mississippi basin east of the Missouri. Its variations in composition and structure, too, are similar to those of the loess of the interior. Its thickness is very variable, and for the most part undetermined, but locally it is at least twenty-five to thirty feet thick, and its maximum is probably considerably more. In many places, as at Bolles Junction (Walla Walla county), it abounds in calcareous concretions of the usual loess type. In other places, as at Alto (Columbia county), it assumes the columnar structure, so characteristic of the loess of some other localities where the formation is well known. In many places, it constitutes the entire mantle rock. In some places it is associated with sand, which may be either beneath it or interbedded with it; and in other localities it contains considerable beds of volcanic ash. The sand and volcanic ash associated with it are sometimes distinctly stratified. In some cases, the stratification is clearly the work of wind, but in others this was not evident. The impression gained was that much of the loess seen is of eolian origin.

Observations on glaciation were made at several points, aside from those enumerated in the preceding pages. Data sufficient for the intelligent direction of future Pleistocene work were

gathered for a number of localities where detailed work in the near future seems desirable. In addition to preliminary studies of this sort, glaciation was found to have occurred in some localities from which it has not heretofore been reported. For example, it was found that glaciers affected the north slope of both the Spanish Peaks of Colorado. These mountains, 12,708 and 13,623 feet high respectively, appear to have represented about the limiting conditions for glaciation, for the glaciers of both mountains were small, and confined to their northern slopes. One of the limiting conditions here was doubtless the small area which could serve as a catchment basin on either peak. Had the areas of these mountains been larger, more considerable glaciation would doubtless have been developed at this altitude.

It was found, among other things, that the detailed study of glacial problems will locally have an important economic bearing. An extensive placer mining plant is being established at Breckenridge, Col., to wash the glacial moraine matter of the Blue River valley, and the gravels of the valley train below.

ROLLIN D. SALISBURY.

Reviews

Preliminary Description of the Geology and Water Resources of the Southern half of the Black Hills and Adjoining Regions in South Dakota and Wyoming. By N. H. DARTON. [Extract from the Twenty-first Annual Report of the U. S. Geol. Surv., 1899–1900, Pt. IV, Hydrography; pp. 489–599; Plates LVIII–CXII; Washington, 1901.]

THE topics discussed in this paper are topography, stratigraphic-geology, geologic structure, geologic history, water resources, minerals, soils, climate and timber. The Black Hills rise out of the Great Plains as a small group of forest covered mountains several thousand feet high. Their central area, composed of mountains and parks, is of crystalline schists and granites. Bordering the old rocks is a belt of limestone plateaus surrounded in turn by the Red Valley, a depression resulting from the etching out of a layer of softer rock — the Spearfish formation of Triassic age. Beyond the valley and concentric with it is the hogback range, due to a hard sandstone not weathered down. Still farther outward are the Plains. Careful descriptions of the lithologic characters and the distribution of each formation follow; in fact the paper is descriptive rather than theoretic, but does not fail to call attention to broad features and to make generalized statements.

The oldest sediments are Cambrian. They are probably of later Cambrian time and give one more item of evidence leading to the conclusion that Cambrian time was one of extensive submergence. Here Cambrian sands were deposited along seashores and in estuaries with gradual submergence and probable ultimate covering of the crystallines with sediments of this age. The chief evidence is the presence of fine grained deposits in the Upper Cambrian such as are not formed near land. At present no Silurian or Devonian strata occur. The reason is problematic. Either there was no deposition or else little deposition and subsequent removal. Carboniferous time began with deep water and marine conditions, and was consummated after the laying down of 800–1000 feet of rock. Triassic and Jurassic are both present and

distinguishable because an abrupt change in the character of the sediments and some erosion occur at the top of the former. Cretaceous sediments have accumulated to the thickness of about 6000 feet and consist largely of shales with some sandstone and a little limestone. Tertiary rocks represented by the White River formation are mostly of clay; fuller's earth, sand, limestone, and grits occur. Still later deposits are classed under earlier and later Pleistocene beds.

The structure of the region is that of an elongated low dome with anticlinal wrinkles or spurs running off from the central area. The maximum uplift was north of Harney's Peak and amounted to 9000 feet.

One of the most admirable features of this paper is the abundance of real geographic material embodied in it. The region described is one of submaturely dissected, domed mountains in which all the sediments have been removed from the central portion leaving subdued hills and broad parks of crystalline rocks. The concentric arrangement of the different formations is due to the uplift and to the processes of erosion which though similar for all strata, have been much more effective in reducing some than others. Soft layers are found etched out, hard layers standing up, but each and every one has its peculiar forms. Thus geography follows stratigraphy.

Attempts by the author, more or less successful, to reconstruct the geography of the locality at different periods and to follow it through its phases, are persistently made, and they yield an interesting element in the work. In this connection there is a contour map showing the present relief of the upper surface of the Dakota sandstone over a part of the area. This kind of work forms a very desirable feature.

The considerable eastward dip away from the Black Hills, where most of the formations outcrop, together with other necessary features, gives good artesian conditions to this region. Many wells reaching the Dakota and Lakota sandstones flow with good water. The scanty rainfall on the plains eastward renders these wells very useful. Many streams diminish or cease by sinkage when they cross the sands. Along Cheyenne and Fall rivers there is some opportunity for irrigation — good bottom lands and reservoir space, with fair water supply.

Soils are mostly residuary from underlying rocks. Overplaced soils and sand dunes are found in places. "Sedentary soils" may be criticised. No soil is sedentary in the sense that it does not move. "Soil in place" or preferably "residual soil" more adequately carries the

meaning. The relation of soils to underlying rocks, and of crops to soils make very instructive points. Considerable mineral wealth is found in coal, gypsum, and lithographic limestone in large slabs. These of sufficient size to be valuable are not obtainable elsewhere in the United States.

The notes and diagrams on climate are good but disappointing because they do not indicate the significance of the condition of the meteorologic elements from a geologic point of view. There is little utility in giving space in a geologic report to climatic notes unless some use is made of them. The climate must have characteristic influence on erosion, soil formation, soil transportation, etc. The position of volcanic ash to the eastward of the volcanoes, now extinct, just west of the Black Hills shows similarity of winds in the White River time to those of the present time.

Why cannot the U. S. G. S. reports, in discussing such a region as this, have a section on geography? It should embrace most if not all of the section here devoted to topography, but should go farther with the question, incorporating some that is said under soils, climate, water resources, etc., and then discuss the influence of relief, soil and water on products, transportation, distribution of plants and animals, man, and his various occupations.

GEO. D. HUBBARD.

EASTERN ILLINOIS STATE NORMAL SCHOOL,
Charleston, Ill.

The High Plains and Their Utilization. By WILLARD D. JOHNSON. [Extract from the Twenty-first Annual Report of the U. S. Geol. Surv., 1899–1900, Pt. IV, Hydrography; pp. 601–768; Plates CXIII–CLVI.]

THE High Plains, as defined in the first chapter, correspond approximately to the Central Plains. They form a belt extending from central Texas northward across Oklahoma and western Kansas into Nebraska, but are more characteristic in Texas because less eroded. By topographic difference they constitute a topographic unit of the great geographic unit—the Great Plains. The High Plains practically have no drainage, hence their surface is in general a dead level known locally as the "Flats."

Chapter II discusses the origin of these plains. They are the

remnants of an old débris apron built in the latter half of Tertiary time, and preserved because of lack of sufficient precipitation to produce run-off. The author takes the ground that this apron of waste was deposited and arranged by streams, but shows that the streams were not of the ordinary type. A careful analysis of arid region stream work leads to the conclusion that "there is no such thing as sheet flow" in the sense of a uniform flood of water and waste, but that the more or less perfect sheet is "one of intimately lacing threads of current."

The deposits of which the plains are composed are the result of this stream work and not of still water work. As proof of the proposition, the author finds the following facts:

(1) Wide distribution, at all depths of gravels, which decrease in size from the mountains. (2) The size of these coarse materials is often that of cobbles. (3) Gravel courses run east and west and are cross-bedded — marking the channel courses of eastward flowing streams. (4) Sand bed salso occur in courses elongated east and west in the "clays." (5) Interlaced stream beds occur as shown where erosion has disclosed them. (6) Even most clay beds are thin and elongated east and west.

Mr. Johnson finds the "mortar-beds" cutting across the local bedding of sands and gravels, and he considers the beds to have been formed by the cementation of the coarse materials at the level of the ground water by salts carried down in the sinking surface water. It appears that his explanation of the distribution of water in these gravels is similar to that of water distribution in the morainic materials of Illinois and Indiana, as worked out by Leverett and others, and stated by Leverett in the Eighteenth Annual Report of the U. S. Geol. Surv. Pt. IV.

Chapter III is a discussion of the "deficiencies of climate." The climate of the High Plains is described as subhumid. It varies from humid to arid through a period of years. The author very properly states that the amount of precipitation is not the only factor in determining the climate, or even the arability of a region. The Dakota wheat fields actually have less rainfall than the Staked Plains of Texas, but the rainfall is more effective in Dakota. In Texas (1) rainfall is more spasmodic; (2) temperature is higher, increasing evaporation and decreasing relative humidity; (3) there are more hours of sunshine, and (4) greater wind movement. In the summary he reaches

two conclusions which are thoroughly borne out by the facts and discussion. (*a*) A truer index of climate than rainfall is relative humidity. (*b*) Observations covering a quarter of a century indicate that no change in climate, save that of short-period oscillations, takes place. While the High Plains area is a climatic unit, it shows evidence of agreement in the series of climatic changes through Pleistocene, with the Great Basin lake fluctuations, and with the advance and retreat of the Rocky Mountain glaciers.

The fourth chapter gives a graphic picture of the boom of 1888–1893, with the subsequent disasters, and some suggestions as to what may be grown on the High Plains.

Chapter V proves the impossibility of general irrigation within the High Plains. The facts are as follows: (1) The rainfall and streams are wholly inadequate; (2) the mountain streams from the west are so loaded with waste that ponds to retain their waters would be exceedingly short-lived; (3) all mountain streams must pass through a broad, arid, fertile strip amply sufficient to utilize all their waters; (4) artesian water in very small quantity is found in the valleys, but the entire supply is altogether too small for general irrigation. This source, however, is sufficient to furnish water for a garden and ranch headquarters at occasional intervals.

In the closing pages there is a discussion of the origin of peculiar sink holes, and a theoretic explanation of the movements of underground waters. This last brings together considerable valuable material which formerly has been scattered and little known, but it presents scarcely anything new.

The author thus states his purpose at the outset, and he accomplishes his object: "To show that the High Plains, except in insignificant degree, are non-irrigable, either from streams, flowing or stored, or from underground sources, and that, therefore, for general agriculture, they are irreclaimable; but that, on the other hand, water from underground is obtainable in sufficient amount for reclamation of the entire area to other uses; that such reclamation has in fact already begun, and is in progress of gradual, but sure development; and that it will be universally profitable."

This paper will be of great service to those in the arid and subarid regions, and to those who may contemplate immigration thither, because it gives authentic information concerning fertility and water-supply there. But the value of the paper is not alone in its descriptive

work. To science the able discussions of causes and effects, of climatic relations to geology, geography, and agriculture, of water-supply, etc., are the most attractive features. The pages devoted to underground water resources are specially strong. The only regret is that the paper is not finished.

George D. Hubbard.

Charleston, Ill.

The Bauxite Deposits of Arkansas. By Charles Willard Hayes, U. S. Geological Survey, Twenty-first Annual Report, Part III, pp. 435–472. Maps and plates.

Commercial deposits of bauxite have been known in Arkansas since 1890, when they were first discovered by the State Geological Survey. The present report by Dr. Hayes represents, however, the first detailed systematic study of these deposits, and its appearance when developments are just beginning in the area, makes it a very timely one.

Preliminary to the description of the Arkansas deposits proper, the report opens with a brief summary of the "distribution of bauxite deposits in the United States." The Arkansas deposits are limited to a small area twenty miles long and five or six miles wide, lying south and southwest of Little Rock, in the adjacent parts of Pulaski and Saline counties. The most important deposits of the state are grouped into two districts, with less important isolated ones between. The general geologic and physiographic relations of the region are recounted in some detail, derived largely, as the author says, from the state survey reports. Three distinct groups of rocks are made out, namely, the Paleozoic sediments in the northwest, the Tertiary and recent sediments on the southeast, and areas of intrusive igneous rocks in the two bauxite districts. The Paleozoic rocks are similarly folded and closely resemble those of the Alabama-Georgia-Tennessee area of the southern Appalachians. The region was probably several times reduced to a nearly featureless plain, and sometime after the folding, probably, during Cretaceous, the igneous rocks were, according to Williams, intruded. Beginning with the Cretaceous, the region was several times invaded by the sea and Tertiary sediments still form a considerable part of the area.

In the detailed description of the deposits, the two districts are

separately described in some detail, and certain peculiarities possessed by each are pointed out. The few scattered isolated deposits are likewise described.

In the Bryant district, which is the most southwesterly one, the bauxite occurs in two distinct forms: (*a*) granitic bauxite, and (*b*) pisolitic bauxite. The granitic bauxite forms the basal portions of the beds, and in most cases rests immediately on a layer of kaolin, derived by the ordinary processes of decay from the syenite. The bauxite is spongy in texture with no trace of the pisolitic structure, but showing partial traces of the granitic structure in which the individual feldspars are replaced by a porus skeleton of alumina. It is probable, says Hayes, that this type of bauxite is in every case derived directly from the syenite by the decomposition of the feldspar and the eleolite, and the removal in solution of silica, lime and alkalis, the alumina alone remaining of the original constituents. The pisolitic type is more uniform than that of the Georgia-Alabama region and forms the upper parts of the beds. The two forms of ore are not separated, as a rule, in the same section, by any sharp and definite line.

In the Fourche Mountain district only the pisolitic type of the ore has been found, which, when nearest the syenite margin, rests on a layer of kaolin as in the Bryant district. Those deposits more distant from the syenite margin are probably interstratified with sedimentary beds of Tertiary age.

The scattered isolated deposits found between the two districts resemble in their mode of occurrence the Georgia-Alabama deposits.

The deposits are in beds or layers, which range in thickness from zero to forty feet, and have a probable average thickness of ten to fifteen feet for the two districts, and two to five feet and more in case of the isolated bodies of ore.

In chemical composition the Arkansas bauxite varies within wide limits. The granitic type is the purest, and in selected samples contains less than 3 per cent. of silica and 1 per cent. of iron oxide, and corresponds in composition to the formula $Al_2O_3 3H_2O$ — the trihydrate of alumina. In the white bauxitic kaolins the silica ranges as high as 20 to 30 per cent., and in extreme cases the iron oxide reaches 50 per cent. in some of the highly ferruginous types of the ore.

Concerning the origin of the Arkansas bauxite deposits Dr. Hayes says that they are so intimately associated with the igneous rocks of the region that genetic relationship between the two is at once sug-

gested. The characteristic pisolitic structure of the upper portion of the deposits indicates chemical precipitation. The granitic bauxite forming the lower or basal portions of the beds, and the bowlders, are evidently of a different origin. The bauxite was probably laid down on the syenite rather than on the kaolin, as there is no indication that the kaolin is an intermediate product between the fresh syenite and the bauxite.

In his report on the igneous rocks of Arkansas Dr. J. Francis Williams suggests two theories for the accumulation of the bauxite. First, that the bauxite was formed by the decomposition of a bed of clastic material, derived principally from the syenite. The second, which he regarded as the most probable one, involved the action of the waters of the Tertiary sea on the still highly heated igneous rocks, in which, under high temperature and pressure, the constituents of the syenite were dissolved and brought to the surface in solution, the water emerging as hot springs. In the discussion of these theories Dr. Hayes points out serious difficulties to both.

In the last part of the report Dr. Hayes treats of the "Economic Relations" under "Development;" "Amount of Ore," which includes a tabular statement of the estimate of the amount of ore in the Arkansas bauxite region, and, according to the author's calculations, shows the total amount estimated in outcrops to be 6,608,500 long tons, and the total amount under cover 43,711,200 long tons; "Quality of the Ores;" and "Mining and Preparation of the Ore for Market."

Thomas L. Watson.

Denison University,
Granville, Ohio.

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